

CERN Proton Synchrotron East Area Facility

Upgrades and renovation during Long Shutdown 2

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CERN Proton Synchrotron East Area Facility

Upgrades and renovation during Long Shutdown 2

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Abstract

In this document, we present the upgrade of the East Experimental Area facility which took place during the Long Shutdown 2 (2019–2021). This document covers the renovation of the East Hall beamlines and infrastructure according to a new layout with the goal of improving the magnet and radiation situation in general. The performance of the new beamlines will be optimized in terms of maximum momentum and choice of particle type. Thanks to a cycled powering mode of the magnets instead of a steady state one, considerable energy savings will be possible. This report summarizes the various detailed studies completed from 2016 to 2019.

Keywords

Experimental areas; injectors; the CERN accelerator complex; test facility

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Executive summary

The main goal of the upgrade was to ensure the long-term operation of the PS East Area experimental area facility. Practically, this was achieved by implementing a new beamline layout, a new cycled powering scheme, and thoroughly refurbishing the associated infrastructure.

To be able to change from a continuous to a pulsed power supply, the yokes of the magnets needed to be laminated. In addition, over the last years of operation, the maintainability of the magnets has been a critical issue, mainly because of long cooldown and repair times and the lack of spares for some magnet families. These two reasons drove the complete renovation of the magnets - to install new magnets with laminated yokes and of fewer families.

In fact, reducing the energy consumption of the facility was also a key point in the launching of the East Area Renovation project. The new beamlines consist of 58 magnets of 12 different types powered by 61 power converters. A significant part of this energy saving is obtained by using a cycling magnet current, hence recovering and storing the magnet energy after each operation. The proposed powering solution is based on the SIRIUS (power System for RapId Regulation with Internal controlled Unit of energy Storage) power converter family, which has been developed especially for Accelerator Transfer Line applications and performs magnet energy recovery after each magnetic cycle.

Concerning maintainability of the remaining equipment, the same approach was used, therefore components such as beam stoppers or collimators were replaced with standard equipment. Beam instrumentation is now modernized using, for instance, (recently developed) beam profile monitors and scintillating fibres. Control of the beamline has been greatly improved with the implementation of a magnet protection system, remote control of the vacuum system, and remotely controlled collimators.

The East Hall (Building 157), which hosts all the primary area, the secondary beamlines, the Cosmic Leaving Outdoor Droplets (CLOUD) experiment, IRRAD and CHARM facilities, as well as the T09 and T10 test beam areas, will be renovated mainly in the North part of the building. In fact, the IRRAD and CHARM facilities remained unchanged as the South part has been fully revamped during the Long Shutdown 2, in the years 2013 and 2014.

To comply with the power consumption reduction, some services such as AC powering and the cooling network were downsized and renewed according to lower operation requirements. Moreover, the shielding of the primary area was completely modified to satisfy radioprotection requirements, and to reduce the time needed to open it in case any equipment needs to be replaced. The access system was adapted to the new configuration and the size of the high activation areas was reduced to limit the exposure of workers during maintenance. The building envelope was completely refurbished to eliminate asbestos and improve greatly its thermal insulation. With regards to the experimental areas (T09, T10, and T11), most of the services were upgraded and include new control rooms, new gas distribution, and dedicated areas for detector/experiment set-up.

Major refurbishment and new installation activities also took place in Building 352, housing the F61 and F62 beamlines, and in Building 251, where the new SIRIUS power converters are located. Indeed, the new technology requires active air and water cooling systems, which were not available in the previous plant.

Undoubtedly the upgrade turned out to be a unique opportunity to bring the facility up to the modern safety standards in terms of radioprotection by implementing dynamic air confinement in the primary area and separating the cooling circuits between activated and non-activated water. On the conventional safety side, the safe operation of the new power converters, which include large energy storage capacitors, and the compliance to ATmosphere EXplosible regulations for the design of the new gas distribution system prevail.

The overall cost to completion of the renovation project amounts to 32 MCHF. Five sixths were dedicated to material expenditures and the rest to personnel. By order of magnitude, the cost drivers were: power converters, magnets, civil engineering, electrical systems, cooling, and ventilation.

The project officially started in July 2016 with detailed study phases in 2016, 2017, and 2018. At the same time as beamline operation in 2018, the civil engineering team has carried out the renovation of Building 157 including walls, windows, and roof. The vast majority of the remaining consolidation activities took place during the Long Shutdown 2 within a 36-month beam-to-beam period. The primary area and the primary beamline area in Building 352 were the most critical and challenging zones with regard to schedule and workload constraints. It is also worth mentioning that the CLOUD run without beam took place in Autumn 2019. Due to the COVID-19 pandemic, the initial schedule has been extended by 6 months, targeting a restart of physics run by October 2021.

For clarification, at the time of writing this report, the project was still in between study and commissioning phases, thus why the predominant verb tense throughout the document is in the future. As of November 1st 2021, all the work in building 352 is concluded, and most of the work regarding the renovation of the hall has been finished. The items that have not been completed concern CLOUD, such as the assembly of the vertical access structure, the control room, and the chemical lab. Building 251 will have further works done on its envelope and building structure.

Chapter 1 Introduction, scope, and schedule

J. Bernhard, S. Evrard, E. Harrouch

1.1 Introduction

1.1.1 Motivation

The East Area of the CERN Proton Synchrotron has served the physics community for over 50 years and remains extremely popular and necessary, among other things, to complete full calibration over a large energy spectrum of the detectors to be installed in the Large Hadron Collider (LHC) experiments according to the needs of the upgrade for the High Luminosity LHC. In addition, physics programs like CLOUD [1], and test facilities such as IRRAD [2] and CHARM [1][3] are based on a reliable and easily maintainable East Area.

A detailed study was carried out over the years 2009–2015 and presented at the Consolidation Day on the 11th of February 2016 [4] following a request to optimize the activities with a focus on what is required for operation in line with the physics community needs.

The East Area renovation is considered as a priority for the Organization and sufficient funds were made available in the Mid Term Plan (MTP) approved by Council in June 2016 to allow the major work to be completed by the end of the Long Shutdown 2 (LS2). Therefore, the Accelerator & Technology Director appointed a project team to take responsibility for the completion of the work.

The East Area renovation covered the refurbishment of the East Hall with its beamlines and infrastructures. A redesign of the beamlines was included to improve the magnet and radiation situation in general. The performance of the new beamlines was improved in terms of maximum momentum and in choice of particle type. Thanks to a cycled powering mode of the magnets instead of a steady state one, considerable energy savings are now possible.

This report summarizes the various detailed studies completed from 2016 to 2019 and outlined in Ref. [5].

1.2 Scope of the renovation

Following the mandate of the Accelerator and Technology Sector Directorate [6], the main goal of the renovation was to ensure the long-term operation of the PS East Area experimental area facility. Practically, this was achieved by implementing a new beamline layout, a new cycled powering scheme, and thoroughly refurbishing the associated infrastructure with the following objectives/means.

The new beamline layout:

- better cope with physics requirements (maximum momentum and choice of particle type (e, h, μ));
- minimize dose rates to personnel, and allow faster repair times by improving equipment accessibility;
- respect today's norms for radiation protection: new primary area ventilation + new dump system.

The new cycled powering scheme:

- replaced massive magnet yokes by laminated ones to allow cycling them;
- installed new SIRIUS power converters with energy recovery capacitor banks;
- allows to reduce the annual electrical energy consumption from 7 to 1 GWh for powering the magnets.

Infrastructure renovation:

- upgraded Building 157 envelope (wall and roof cladding) with a particular effort on thermal insulation, allowing for an annual energy consumption reduction from 3 to 1 GWh;
- sanitized the building and got rid of asbestos;
- separation of primary and secondary beams and zones cooling circuits.

A new beamline layout, as illustrated in Fig. 1-1, which addresses most of the issues related to the previous layout.

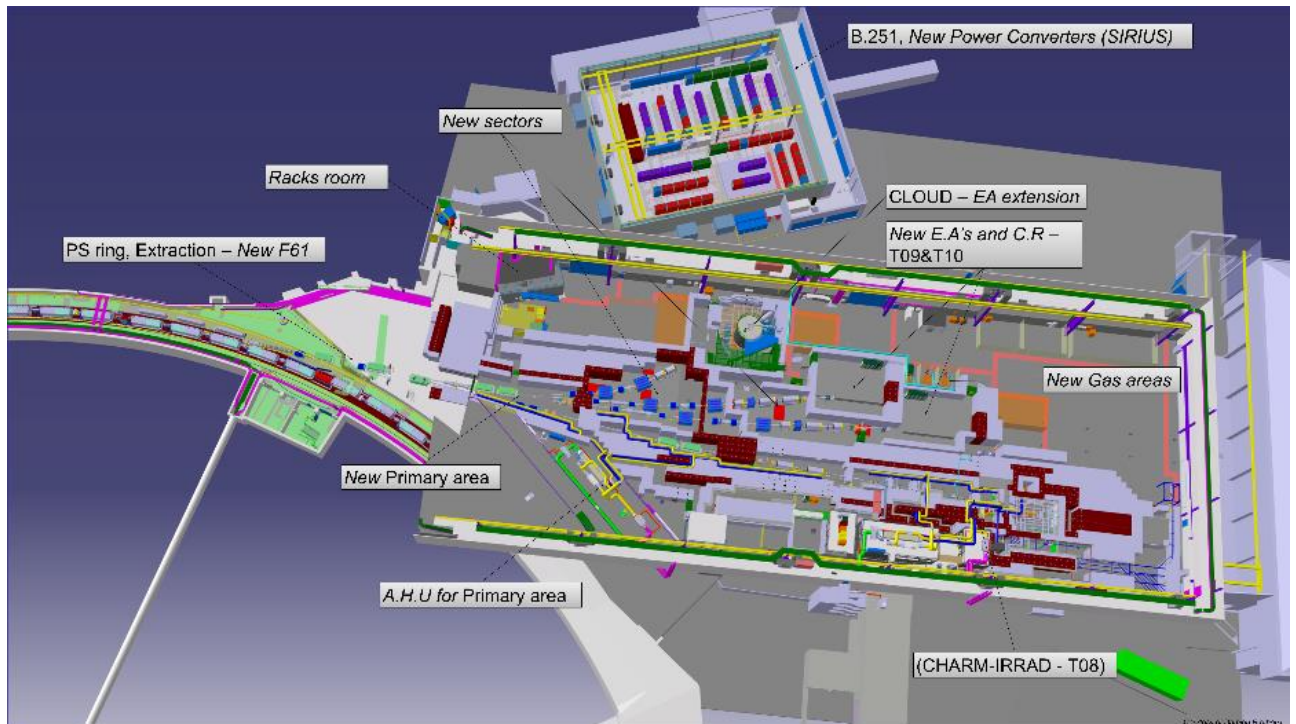


Fig. 1-1: New layout of the East Area.

1.2.1 *Beamline: design and layout*

Before renovation, the primary beam was extracted from the PS into the F61 beamline and could be sent either to the T08 beamline used by IRRAD and CHARM or to the north target to produce secondary beams for the experimental areas (T09, T10, and T11), as can be seen in Fig. 1-2.

After renovation, the primary beamline of the IRRAD/CHARM main parameters and optics remained nearly unchanged. These parameters can be consulted in Table 1-1.

The North branch of the beamlines was modified to host two targets and allow a better performance of the secondary beamlines (particle selection, maximum momentum, etc.).

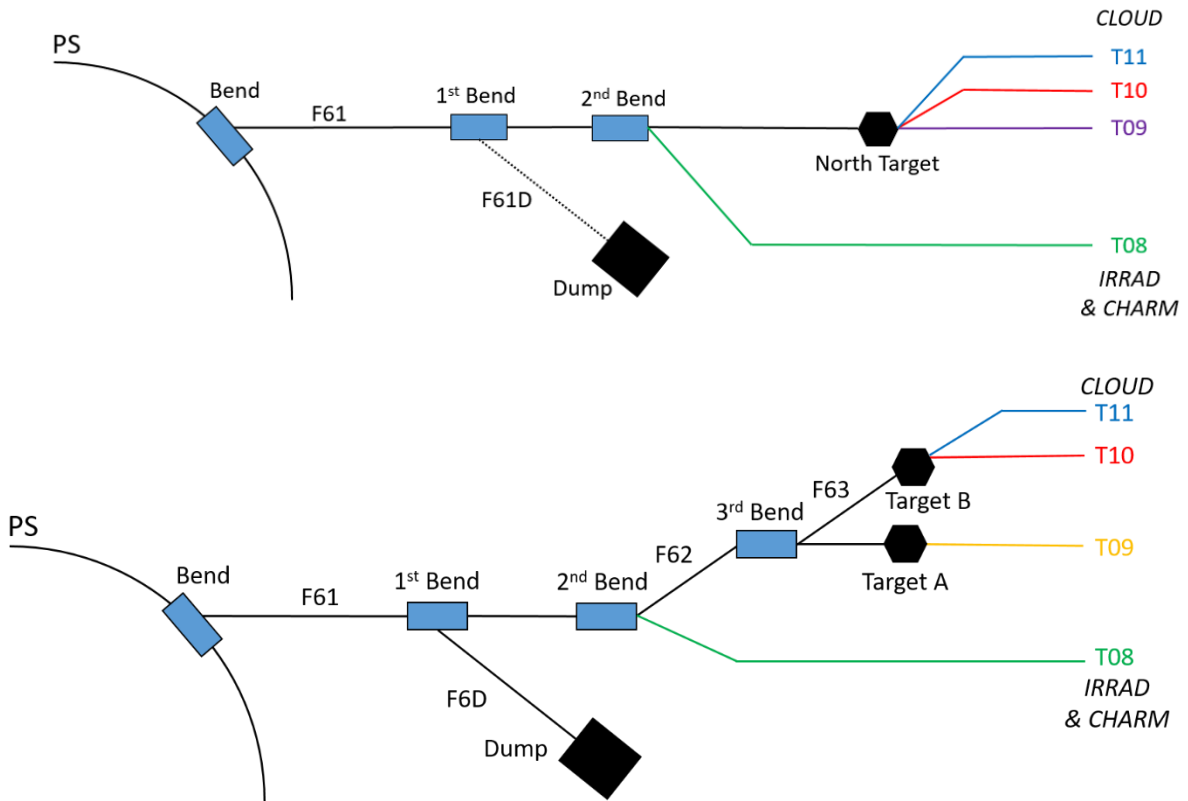


Fig. 1-2: Schematic view of the layout in the East Area before (top) and after (bottom) renovation.

Table 1-1: Main parameters of the primary beam.

Parameter	Value
Proton beam momentum [GeV/c]	24
Maximum # spills per typical super-cycle	6
Duration of typical super-cycle [s]	45.6
Maximum # protons per second	6.7×10^{10}
Maximum assumed number of days of operation per year	200
Assumed efficiency	90%
Maximum number of super-cycles per year	340 000
Maximum number of protons per year	1.0×10^{18}

In the new design, the secondary beams are produced at target B for T10 and T11, and target A for T09 with a vertical angle of 30 mrad with respect to the primary beam. This allows for clean stopping of the primary beam (the part which does not interact with the targets) into a dedicated beam dump independently of the secondary beams. In the pre-LS2 configuration, the primary beam was dumped in the magnets themselves (causing high residual radiation and ageing of beamline components). The beam parameters for the new T09 and T10 beamlines are presented in Table 1-2. It should be noted that the new T11 beamline has a maximum momentum of 3.6 GeV/c as before.

Table 1-2: Beam parameters for the new T09 and T10 beamlines. For convenience, a comparison to the old T09 values is given in addition.

Parameter	T09 (old)	T09 (new)	T10 (new)
Length up to the last element [m]	54.3	50.2	44.7
Max. momentum [GeV/c]	10	15	12
Momentum resolution	0.7 %	0.7 %	0.7 %
Max. momentum band		±15 %	±15 %
Horizontal acceptance	±4.8	±4	±5
Vertical acceptance	±4	±3.8	±3
Horizontal magnification at final focus	0.81	0.86	0.92
Vertical magnification at final focus	0.91	0.9	0.58
Max. flux per spill	10 ⁶	10 ⁶	10 ⁶

1.2.2 *Beamline: Hardware*

To be able to change from a continuous to a pulsed power supply, the yokes of the magnets needed to be laminated. In addition, over the final years of operation, maintainability of the magnets became a critical issue mainly because of long cooldown, repair times, and the lack of spares for some magnet families. These two reasons drove the need for the complete renovation of the magnets in order to install new magnets with laminated yokes and of fewer families.

With the same philosophy concerning maintainability, components such as beam stoppers or collimators were replaced with standard equipment. Beam instrumentation were also modernized using, for instance, (recently developed) beam profile monitors and scintillating fibres.

Control of the beamline was greatly improved with the implementation of a magnet protection system or remote control of the vacuum system and remotely controlled collimators.

1.2.3 *Buildings 157, 251, and 352: infrastructure consolidation*

Building 157, which hosts the primary area, the secondary beamlines, the CLOUD experiment, the IRRAD and CHARM facilities, as well as the T09 and T10 test beam areas was renovated mainly in the North part of the building. In fact, the IRRAD and CHARM facilities remained unchanged as the south part had already been redone in 2013–2014.

To comply with the power consumption reduction, some services such as AC powering and the cooling network were downsized and renewed according to lower operation requirements.

To cope with the new optics, the shielding of the primary area was completely modified to satisfy the radioprotection requirement, and to reduce the time needed to open it in case an equipment needs to be exchanged.

The access system was also renewed and the size of the high activation areas was reduced to limit the exposure of workers during maintenance.

The experimental area services were upgraded (T09, T10, and T11): new control rooms, new gas distribution, dedicated areas for detector/experiment set-up, etc.

The building's envelope was completely refurbished to eliminate asbestos and improve greatly the thermal insulation within the building.

Building 352, which houses part of the PS ring and the extraction line towards the East Hall, saw most of the modifications in the F61–F62 and F6D beamlines. Following the renovation strategy, these lines were also renovated (new magnets and power converters, standard beam stoppers, etc.). The infrastructure remains generally identical but required a new cooling circuit and new cabling to match the new layout.

Building 251, which hosts all the power converters, was renovated to adapt to the new configuration and requirements of the new beamlines.

The previous power converters had become unreliable and were replaced by different types of modern SIRIUS power converters, including SIRIUS S, 2P, 4P, and 4P+. Since these new power converters have different characteristics (weight, size) compared to the old ones, the structures on which these converters are installed, the electrical supply system, and the cooling system was redone during the renovation.

In particular, the following actions took place during the renovation in LS2:

- i) Renewal of the false floor to support all the power converters.
- ii) New cooling network and ventilation dedicated to the power converters.
- iii) Renewal of the electrical infrastructure to provide AC current to the power converters.
- iv) Re-organization of the DC cabling to connect the power converters to the magnets in Building 157.

1.3 Project cost and schedule

1.3.1 Project cost

The cost to completion of the renovation project budget amounts to 30 MCHF. Four fifths are dedicated to material expenditures and the rest to personnel. In order of importance, the cost drivers are power converters, magnets, civil engineering, electrical systems, cooling, and ventilation.

1.3.2 Schedule

The project officially started in July 2016 with detailed study phases in 2016, 2017, and 2018. In parallel to 2018 beamline operation, the Site Management and Buildings department carried out the renovation of the whole of Building 157 including walls, windows, and roof. The vast majority of consolidation activities took place during the Long Shutdown 2 within a 36-month beam-to-beam. The primary area and the primary beamline area in Building 352 were the most critical and challenging zones with regards to schedule and workload constraints. It is also worth mentioning the CLOUD runs without beam, which took place in Autumn 2019. Due to the Covid-19 pandemic, the initial schedule has been extended by 6 months, targeting a restart of physics run by October 2021.

1.4 Safety

The renovation of the East Area has ensured that the present level of safety is maintained and improved (whenever possible) during all project phases (from the design phase until the operation of the facility). This will be demonstrated in a dedicated safety file. The main objectives of the project in terms of safety are the following.

- i) Reduce the exposure to ionizing radiation during the maintenance of the facility (especially the primary area).
- ii) Bring the facility up to the modern safety standard in term of radioprotection (dynamic confinement in the primary area, separation of cooling circuits, etc.) and conventional safety (refurbish the obsolete electrical infrastructure, reduce the risk of falling, etc.).
- iii) Design an adequate system to safely operate the facility in its new configuration (new access systems, beam intercepting devices, safety matrixes, etc.).
- iv) Ensure the structural resistance of all the shielding assemblies.
- v) Ensure the safe operation of the new power converters which include large energy storage capacitors.
- vi) Respect the ATEX regulations for the design of the new gas distribution system.

References

Some EDMS documents referenced in this report can be access restricted, access to those can be requested through the EDMS platform.

- [1] CLOUD Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=PS215>, last accessed May 22nd 2019.
- [2] F. Ravotti *et al.*, A new high-intensity proton irradiation facility at the CERN PS East Area, *PoS TIPP2014* (2015), 354, <http://dx.doi.org/10.22323/1.213.0354>
- [3] CHARM Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=EA-IRRAD+Mixed-Field>, last accessed May 22nd 2019.
- [4] ATS Consolidation Day, 11 February 2016, link to presentations: <https://indico.cern.ch/event/492100/>.
- [5] L. Gatignon, The East Area upgrade - specifications and cost estimates, [EDMS 1471844](#) (2015).
- [6] F. Bordry, East Area renovation project mandate, [EDMS 1715122](#) (2016).

Chapter 2 East Area renovation: Motivations and general description

J. Bernhard, S. Evrard, L. Gatignon, E. Harrouch, H. Wilkens

2.1 General description of the East Area before and after Long Shutdown 2 (LS2)

The East Area is one of the oldest experimental areas at CERN: the first implementation dates from the early 1960s. The experimental area itself is located in Building 157 on the Meyrin site and surrounded by a number of associated service buildings (Fig. 2-1), including Buildings 251 and 263, which house the power converters.



Fig. 2-1: Aerial view of the East Area buildings.

Already before renovation (Fig. 2-2), the proton synchrotron (PS) extraction (F61) located in Building 352 provided 24 GeV/c protons to the East Area. It provided slowly extracted primary proton beams to the so-called T8 proton IRRADiation facility (IRRAD [1]) and CERN High energy AcceleRator Mixed field facility (CHARM [2]). The last part of T08 together with IRRAD and CHARM was renovated during LS1. The second branch, F61N, allowed protons to be sent onto the so-called North target, from which three simultaneously running secondary beams were derived: T09, T10, and T11. The T09 and T10 beamlines were used as general-purpose test beams, which, due to their design and also due to technical restrictions, were limited to 10 and 6 GeV/c respectively. The T11 line had a maximum beam momentum of 3.6 GeV/c and was most of the time used by the Cosmic Leaving Outdoor Droplets (CLOUD [3]) experiment. A synoptic of all these beamlines is shown in Fig. 2-3 with indication of maximal momentum. The two primary proton branches were operated in alternation, and each had its own dedicated 2.4 seconds PS cycles. The beam intensities were of the order of $3-4 \times 10^{11}$ protons per PS cycle for the primary beams and up to 10^6 particles per cycle for the secondary test beams.

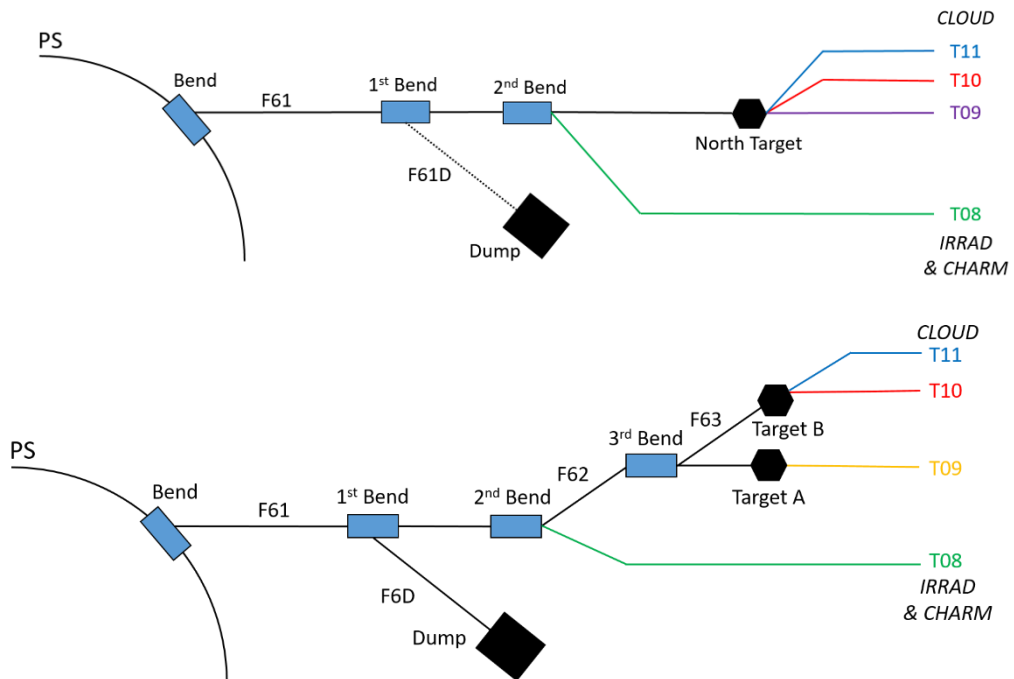


Fig. 2-2: Schematic view of the layout in the East Area before (top) and after (bottom) renovation.

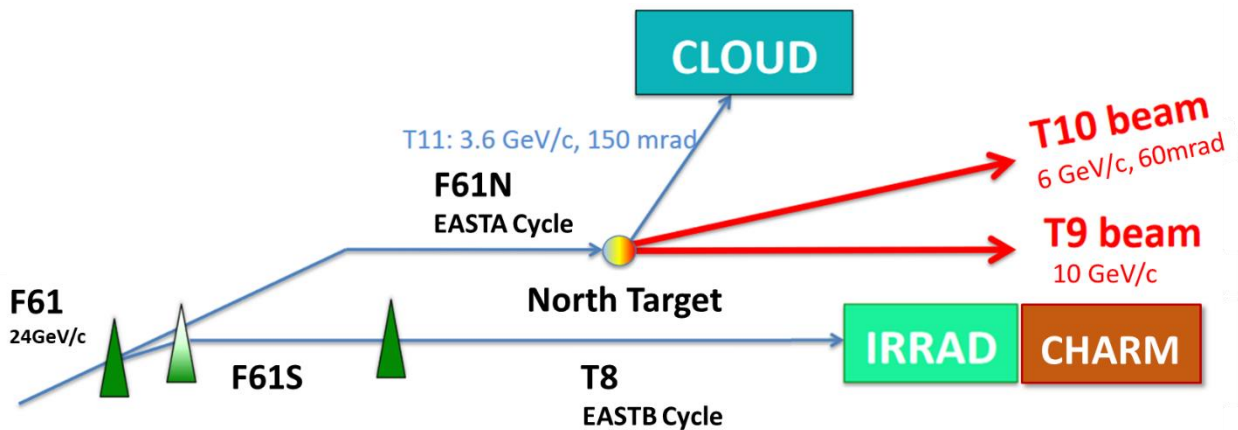


Fig. 2-3: Schematic view of the beam layout in the East Area before renovation with beam energies.

The users controlled their test beams themselves from a common local control room, the East Beam Control Room (EBCR), inside Building 157. PS operators controlled the primary beams from the CERN Central Control room. Certain equipment, e.g. collimators and vacuum, were only controllable locally from the EBCR. The layout of the East Hall in its pre-LS2 configuration is shown in Fig. 2-4.

Over the years the East Area has served, in addition to the CLOUD experiment and the irradiation facilities IRRAD and CHARM, a multitude of test beam users. Recently, T10 was mostly used by the ALICE [4] collaboration, whereas T09 served many different users, from the Super Proton Synchrotron (SPS) or Large Hadron Collider (LHC) experiments but also linear collider, space experiments, and R&D projects from all over the world. Due to serious over-booking of the Experimental Hall North 1 (EHN1) test beams in the SPS North Area, the East Area is getting increasingly popular.

The new layout after renovation (Fig. 2-2) presents a similar layout: the F61 line provides protons from the extraction of the PS to the East Area. The first bend in the F61 line sends the protons to the F6D line with

a dump placed at the end used for PS extraction test beams. The protons will be deviated after the second bend to T08 and the irradiation facilities CHARM and IRRAD; or they will be deviated through F62 to the other lines. T09 will be still used as general-purpose test beam and will receive the beam after target A. If not present in T08 and T09, the beam will go through F63 to target B and will serve the T10 and T11 lines. T10 will be used like T09 as a general-purpose test beamline, however, T11 will always host the CLOUD experiment. A general detailed description of the line with physics calculation is available in Section 2.3.

2.2 Problems in the East Area

Over the last decade the exploitation of the East Area has been hampered by a number of technical problems and restrictions, mostly (but not only) related to magnet failures. Many of the 63 magnets installed in the East Area are very old (up to 50 years) and belong to 22 different families, in many cases without spare magnets being available.

Many of the critical magnets are located in a heavily shielded ‘primary area’, for which no ventilation system is available. The production of ozone due to the passage of the beam through air has certainly contributed to the degradation of the magnets, in combination with the high radiation levels. Whenever a magnet in that area fails, the East Area must be stopped for a period of several weeks (one week to open the 6 metre thick roof and at least one week to fix the magnet itself).

Some critical magnets in the F61 and F61S branches are located in the PS ring zone. Their accessibility is very difficult as well, so that an intervention takes at least a week during which the PS (and hence also the SPS and LHC!) must be stopped.

One important incident occurred in 2004, when the MNP23 magnet in F61S failed after 30 years of service, due to erosion induced blockage of its water circuits. During the 2006–2007 annual stop, the septum magnet was replaced by a C-shaped bending magnet (MCB [5]), which is pulsed between EASTA and EASTB cycles (Fig. 2-3). This allows all beamlines to be operated, but the option of running the irradiation facilities and the test beams simultaneously on the same PS cycle was lost. This, aggravated at the same time by root-mean-square power restrictions on the aging PS main power supply and thereby on the maximum number of East Area cycles, has led to reduced cycle efficiency for the East Area exploitation with, in particular, a severely reduced duty cycle for the test beams.

In 2010, the start-up of the East Area was delayed by more than two weeks because the MNP23 magnet in T09 had to be replaced by a spare magnet, which has been modified to hopefully reduce the risk of short circuits. As the new magnet showed some water leaks from the start, it was decided to lower the top momentum of the T09 beam from 15 to 10 GeV/c. In 2011, the T10 beam had to be stopped 10 days before the end of the proton run due to a failure of its first bending magnet.

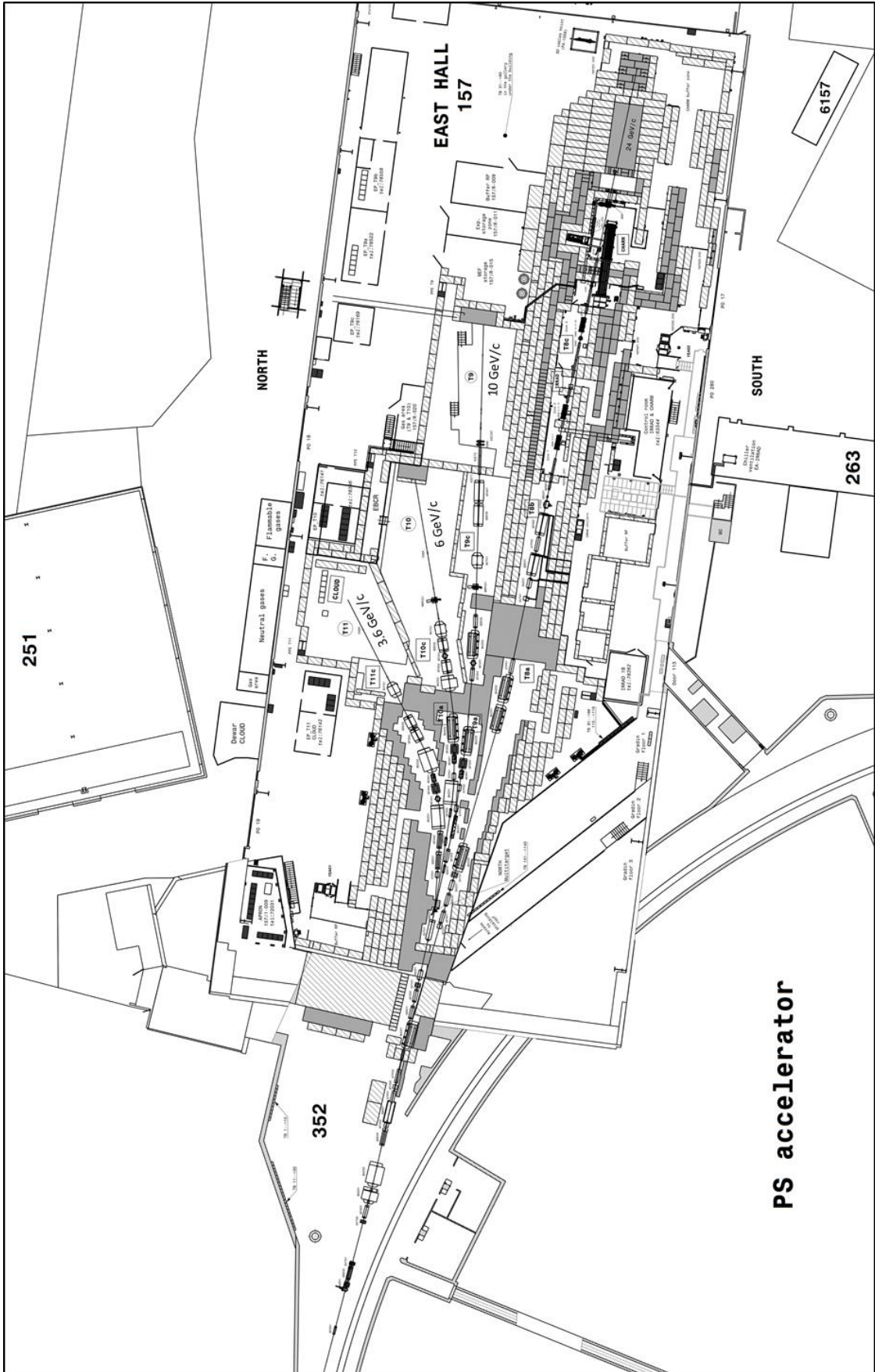


Fig. 2-4: The 2018 layout of the East Area.

Also, a number of quadrupoles were causing worries. Three Q120 type quadrupoles had to be replaced in the 2008/2009 shutdown. Two Q800 type quadrupoles could no longer operate at their nominal current since the inlet temperature of the cooling water had been increased by a few degrees. The top momentum of the T10 beamline had correspondingly to be decreased from 7 to 6 GeV/c.

A number of magnets are quite radioactive. This concerns, in particular, the quadrupoles at the beginning of the secondary beamlines and T09 first bending magnet and its surroundings. In fact, the protons that traverse the North target without interacting are lost inside the magnet itself or just downstream of it, in uncontrolled conditions. The whole environment has therefore high radiation levels. At this point it should be pointed out that this magnet is the most critical magnet in the whole East Area.

2.3 Physics justification

The research and development activities pursued at the East Area are articulated along three main themes: fundamental physics experiments, beam tests for detector R&D and experiments (like NP), and proton and mixed field irradiation activities.

2.3.1 Fundamental physics experiments

Over the last 20 years, the East Area housed four physics experiments: HARP [6], DIRAC [7], CLOUD, and P349 [8]. HARP (PS214) was studying the hadron production of protons on a number of nuclear targets, to constrain predictions of the neutrino fluxes at experiments such as MiniBooNe and K2K, performed from 2000 to 2002. The DIRAC experiment (PS212) aimed at measuring the lifetime of pionic atoms, to observe Kaon atoms and to measure their lifetime. DIRAC took data over many years and was completed in 2012. The CLOUD (PS215) experiment uses a special cloud chamber to study the possible link between galactic cosmic rays and cloud formation. This is the first time a high-energy physics accelerator has been used to study atmospheric and climate science. The results are contributing much to our fundamental understanding of aerosols and clouds, and their effect on climate. CLOUD is in full swing and will continue for many years. P349 took data in 2014 and 2015, to study polarization in the anti-proton production process, in view of applications in the production of polarized anti-proton beams. The East Hall is the only location where new experiments can be proposed at the PS.

2.3.2 Test beam for detector R&D

The test-beam program in the East Area covers all aspects of detector R&D in the high-energy physics field: from collider and fixed target experiments (detector R&D for LHC, linear colliders, North Area, GSI, etc. experiments), through cosmic ray detectors to be flown on balloons or satellites (PAMELA [9], AMS [10], GLAST [11], PEBS [12], etc.), to emulsions and detectors to be used in neutrino or dark matter searches (MINOS [13], OPERA [14], SHiP [15], baby-MIND [16], etc.). Throughout the conception cycle of new particle detectors, the needs for test-beam campaigns are numerous, from the tests of new concepts, the characterization of first prototypes, the validation of final designs, and the calibration and performance assessments of the production modules.

The test beams in the East Area are as popular as ever, in spite of the low duty cycle for their operation. This is illustrated in Fig. 2-5. Over time, less beamlines have been available for test beams as the irradiations and experiments have been using more of the beam time on their dedicated beamlines.

The test-beamlines in the East Area are complementary to the test-beamlines at the SPS North Area, as they allow significant flux in the energy range not or hardly covered in the North Area (typically limited to ≥ 10 GeV/c). Some experiments prepare their set-up in the East Area before running in the North Area. In addition, some users that prefer the North Area beams accept running in the East Area, as the North Area beamlines are increasingly over-booked.

Recently, users are more willing to come to the East Area since some minimal beam instrumentation has been added (a scintillator and a delay wire chamber) at the end of each beam. This has further improved with the introduction of a modern beam control system.

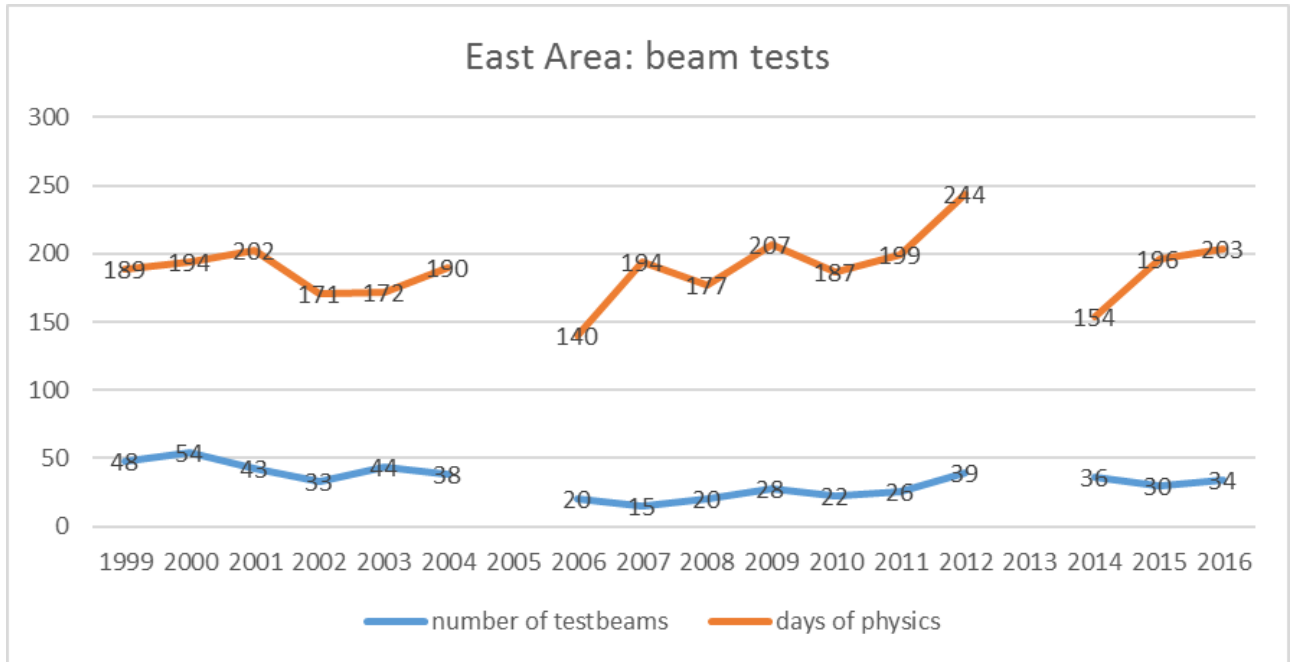


Fig. 2-5: Number of tests beam in the East Area and number of days of test beam operation.

The East Area is thus indispensable, both for the users with needs for the lower energy test beams (such as ALICE, CBM [17], PANDA [18], etc.) and to cope with the overbooking of the EHN1 beams. However, some users consider the East Area beamlines unsuitable, because there is no energy overlap with the beamlines in the North Area. For them, the beamlines would be more usable only if the top momentum were well above 10 GeV/c and if there were more selectivity in particle type (electrons, hadrons, muons) as with the North Area beamlines.

An important advantage of the East Area is also the short distance between control rooms and the test beam areas, therefore allowing short cable lengths. The access to the test areas is much faster (< 15 seconds for the movement of the beam stoppers) than in many of the EHN1 beams where the movement of the beam dumps may take up to 6 minutes!

2.3.3 Irradiation facilities

Next to the test beams, the East Hall hosts the EA-Irradiation facility addressing the needs of the community for proton irradiations and for mixed field irradiation (Radiation To Electronics (R2E) project).

The proton irradiation facility was designed and built driven by the need to qualify detectors and materials for the increasingly harsh environments of the experiments at the LHC, which had to cope with the doses induced by the design luminosity of 300 fb⁻¹, and will have to develop detectors resisting the doses induced by 3000 fb⁻¹ proton–proton collisions, as illustrated in Fig. 2-6.

Up to 2012 proton irradiations were performed in the T7 beamline, alternating beam time with test beams, until 2009, and this was the unique use from then on as the needs for irradiations grew. R2E had been served by several parasitic facilities, such as a location behind the T6 target in TCC2, CNRAD, and H4IRRAD. These facilities suffered from difficult access conditions and/or lack of flux. During Long Shutdown 1, a dedicated facility in the East Area was thus build, with support from the EU AIDA funding, to satisfy the needs of the proton irradiation and R2E project.

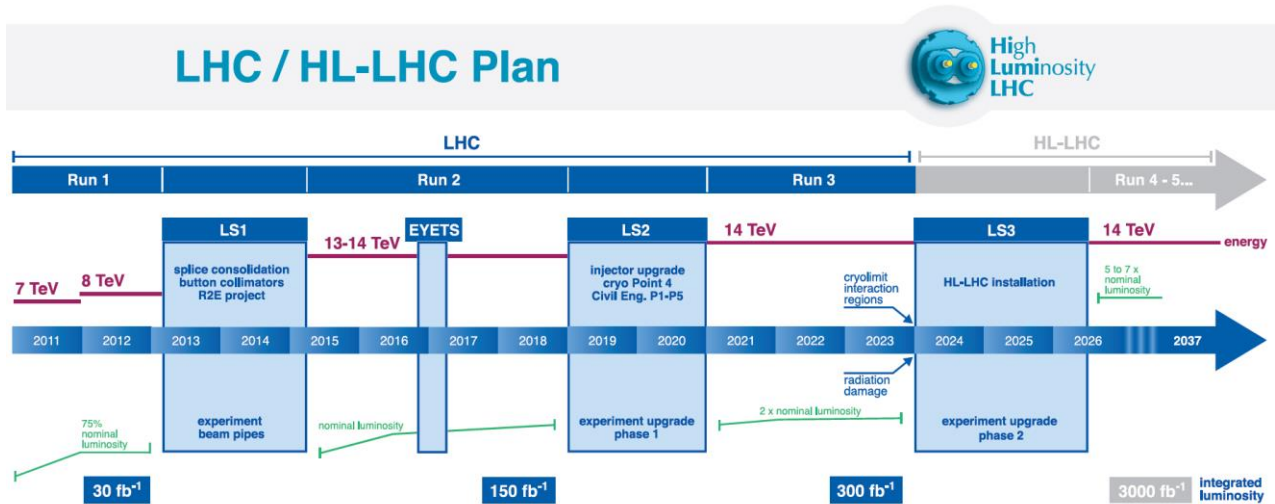


Fig. 2-6: Planned luminosity increase for the LHC accelerator.

This combined facility is installed in the zone once occupied by DIRAC, and profits from a number of important advantages with respect to its precursor in the T7 line, as listed below.

- i) There is significantly more space and infrastructure available, allowing for the housing of large objects connected to power and cooling water.
- ii) The shielding allows for higher integrated fluxes for the irradiations.
- iii) The infrastructure is adapted properly to the needs of an irradiation facility.
- iv) The access is a lot easier and, most importantly, no longer requires a long stop of the whole East Area. Also, in the new layout, access exposes the personnel to much lower doses.
- v) The same proton cycles serve at the same time the proton irradiation facility, formerly installed in T7, and the mixed field facility in T8 previously behind DIRAC.
- vi) There is more freedom in optimizing beam conditions for the proton irradiations than in T7 (the presence of several quadrupoles in the T8 line gives flexibility in focusing).

With the LHC program running well into the next decades, the needs for the EA-irradiation facilities have been established for many years to come. The needs of test beams, both for the LHC experiment upgrade programs, and also for all the larger high-energy physics community, for instance, the development of detectors for neutrino physics or dark matter searches, and the current physics experiment conducted in the East Hall require the East Hall to remain functional. Finally, the East Hall is the only location to host new experiments to be proposed at the PS.

2.4 Motivations and guiding principles for the new design of the East Area

This project is justified by:

1. The unique importance of the East Area for physics and test beams:
 - optimize the general layout of Building 157 to provide all the services needed for the experiments and allocate sufficient space for set-up in the test beam area itself and for storage purposes;
 - improve the performance of the beamlines with increased control over beam particle type and higher maximum beam momenta for T09 and T10 (15 and 12 GeV/c respectively, to be compared with 10 and 7 GeV/c now), allowing overlap with the momentum range of the EHN1 beamlines.

2. The extremely poor state of equipment, in particular magnets and power converters. On top of that, repairs are extremely costly in terms of manpower, radiation dose, and beam time (impacting also the PS, SPS, and LHC in some cases). The new design will:
 - use fewer types of magnets with sufficient spares and considered reliable by the magnet group. In particular, splitter magnets and delicate septum magnets must be eradicated;
 - optimize access to the beamline elements by restricting the primary area to the minimum size possible, reducing the time needed to open the shielded areas and the equipment density in all the areas;
 - replace the beamline components by standard systems (vacuum, collimators, beam stoppers, interlocks, etc.) to ease their maintenance and ensure their long-term operation.
3. The non-conformity of the area to modern safety standards (e.g. electrical, presence of asbestos, etc.) and to radioprotection requirements. The new design will:
 - bring the area up to modern standards from a radiation protection, safety, and instrumentation point of view;
 - restrict high radiation levels to those locations where they cannot be avoided. Dump the unused primary protons cleanly and as soon as possible after the two targets in a re-entrant dump;
 - refurbish the building envelope to eliminate the presence of asbestos and improve the thermal insulation of the building.
4. The reduction of the energy consumption of the facility. The new design will:
 - implement a cycled powering mode of the magnets instead of a steady state one allowing considerable energy savings in terms of electricity. Therefore, new generation SIRIUS power converters will be used and fitted with capacity banks for energy recovery between the various magnet cycles;
 - size the general services (cooling, ventilation, and electrical infrastructure) to optimize the energy consumption of the facility.

A new layout is proposed, as illustrated in Fig. 2-7 which addresses most of the issues related to the existing layout. The beam design related options have been based on discussions with a number of physics coordinators, with the technical groups and representatives of the East Area experiments, and with representatives of the main East Area test beam users.

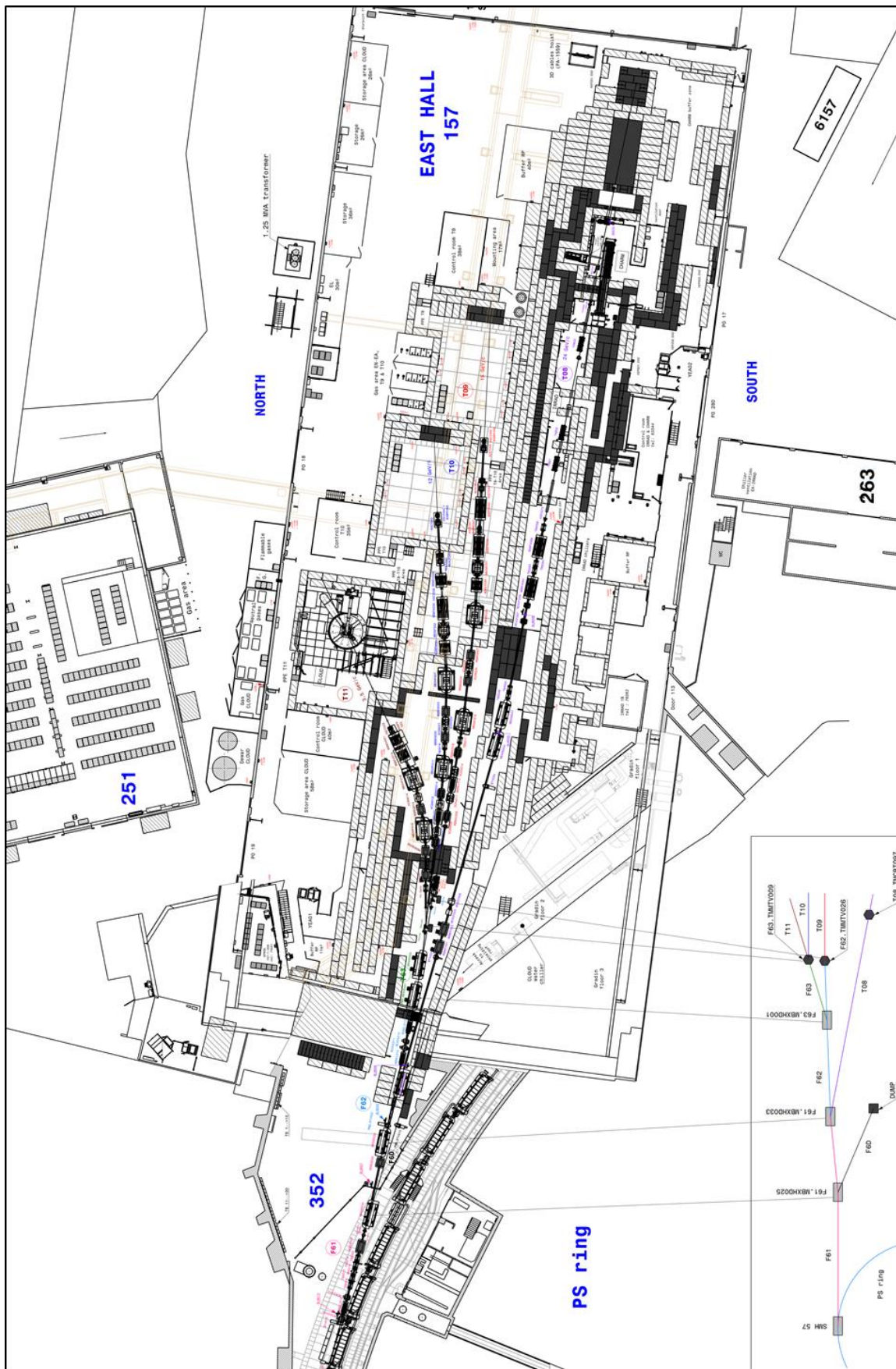


Fig. 2-7: Proposed new layout of the East Area.

References

- [1] F. Ravotti *et al.*, A new high-intensity proton irradiation facility at the CERN PS East Area, *PoS*, **TIPP2014** (2015) 354, <https://doi.org/10.22323/1.213.0354>.
- [2] CHARM Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=EA-IRRAD+Mixed-Field>, last accessed May 22nd 2019.
- [3] CLOUD Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=PS215>, last accessed May 22nd 2019.
- [4] ALICE Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=ALICE>, last accessed May 22nd 2019.
- [5] Specification of the bending magnets for the ISR beam transfer system, ISR/BT group (I-5010-ISR) (CERN, Geneva, November 1967), [EDMS 1100428](#).
- [6] HARP, Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=PS214>, last accessed May 22nd 2019.
- [7] DIRAC Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=PS212>, last accessed May 22nd 2019.
- [8] P349 Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=P349>, last accessed May 22nd 2019.
- [9] PAMELA Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=RE2B>, last accessed May 22nd 2019.
- [10] AMS Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=AMS-RE1>, last accessed May 22nd 2019.
- [11] Wood *et al.* (GLAST Collaboration), *Bulletin of the AAS* **27** (1995) 1387. <http://adsabs.harvard.edu/abs/1995AAS...187.7120W>
- [12] P. von Doetinchem *et al.* *Nucl. Instrum. Meth.* **A581** (2007) 151, <https://doi.org/10.1016/j.nima.2007.07.053>
- [13] A. Habig *et al.* (MINOS Collaboration), The MINOS detectors, 29th International Cosmic Ray Conference (ICRC), Pune, 2005, pp. 319–322, [arXiv:hep-ex/0507018](https://arxiv.org/abs/hep-ex/0507018)
- [14] OPERA Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=CNGS1>, last accessed May 22nd 2019.
- [15] SHiP Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=SHiP>, last accessed May 22nd 2019.
- [16] Baby-Mind Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=NP05>, last accessed May 22nd 2019.
- [17] CBM Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=RE21>, last accessed May 22nd 2019.
- [18] PANDA Greybook: <https://greybook.cern.ch/greybook/experiment/detail?id=RE22>, last accessed May 22nd 2019.

Chapter 3 Design of the East Area facility after renovation

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3.1 Beamline design and layout

3.1.1 Introduction

The PS primary proton beam is slowly extracted at 24 GeV/c towards the East Area with the help of the third-order resonance technique over a typical spill length of 350 to 450 ns within 2.4 s cycles. The number of East Area extractions is usually around five to six per overall PS super-cycle of typically 40 s and depends on both users and schedule constraints, respectively. After passing both magnetic septa SMH57 and SMH61 (Fig. 3-1) in the PS, the beam enters the F61 transfer line that transports the beam either to the so-called North Targets via the lines F62 and F63 or towards T08, which serves the irradiation facilities IRRAD and CHARM. During operation of primary ion beams, only these irradiation facilities can be operated. The principle of extraction by third-order resonance and the corresponding optical elements inside the PS, such as the magnetic septa, will be kept unchanged for the new East Area operation. Thus, only a replacement of the existing magnets by laminated versions with slight optimization of the optics was chosen as the renovation baseline for F61 with changes in the layout mostly due to integration constraints and considerations for improved radiation protection. In particular, all the main horizontal bends have been replaced by reliable and robust MCB magnets, which are available with sufficient spares and can be operated in pulsed mode. The splitting option, although more efficient for operation, was dropped in 2005 for technical reasons that were hard to overcome in a reliable manner. For further details on the recent operational history of F61 and the original ideas of the renovated East Area beams, see Ref. [1].

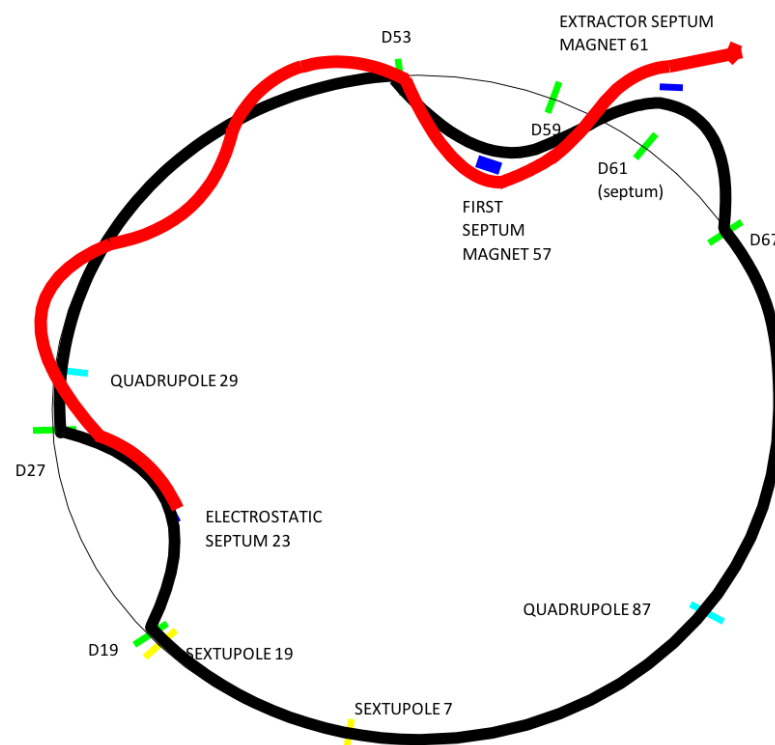


Fig. 3-1: Employed slow extraction scheme in the PS ring towards F61; courtesy: R. Steerenberg, ‘Proton Beams in the East Area’, OP course material, 2004.

3.1.2 The F61 transfer line matching section

The matching section of F61 uses a frontend of four quadrupole magnets to match the extracted beam for further transfer. As the beam is horizontally extracted and thus horizontally large, at the start, strong and compact focussing quadrupoles are required with a large horizontal aperture. While three Q74 magnets were used in the old layout, only one laminated Q74 magnet will be used in the new design (F61.MQNCL007), therefore reducing space restrictions in the very dense area between the PS main combined elements and allowing for a better spare situation for this purposely made magnet. The first quadrupole is then followed by a set of five beam stoppers that are used as safety elements during access to the zones downstream. Afterwards, a triplet of quadrupoles follows (F61.MQNEL014, F61.MQNEF021, and F61.MQNEG030), which matches the beam towards either F62 or T08.

Inside the triplet, after F61.MQNEF021, the M100 and M200 dipoles have been replaced by a single C-shaped MCB magnet (F61.MBXDH025). At full current and inversed polarity, this magnet deflects the beam towards the F6D dump position, which is required by Operation Group (BE-OP-PS) for setting up the slow extraction. In nominal operation, F61.MBXHD025 in combination with F63.MBXHD001 provides a magnetic chicane that enlarges the space between F61 and T08. This ensures enough space for the installation of two North Targets instead of one. The destination of primary proton beam is chosen with the help of F61.MBXHD033, which replaces the unreliable SMH01 splitter magnet. At zero field, the beam is transported towards the North Targets, while at full field the beam is directed towards T08.

3.1.3 Transport towards the North Target – F62 and F63

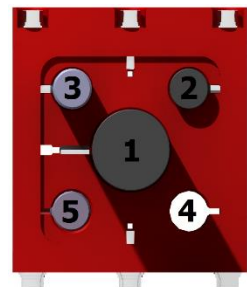
A doublet of Q120C quadrupoles is used to focus the beam on the respective secondary targets. The F63.MBXHD001 MCB-type dipoles correct the angle introduced by F61.MBXHD025, while another MCB-type dipole (F63.MBSHD005) switches between the target locations, again with field off (target A serving T09) or field on (target B serving T10/T11).

For both targets, the multi-target design chosen was introduced originally in 2014. Each target has five target heads, each with a diameter of the order of 1 cm (see Table 3-1). The layout of the target region is shown in Fig. 3-2, where the primary beam enters from the left side. In order to avoid changes in the main dipole currents and to separate initial position matching the F61 correctors from steering on the targets, another set of CR200 corrector magnets was introduced: F62.MCXCE013 for horizontal corrections and F62.MCXCE013 for vertical corrections. Figures 3-3 and 3-4 illustrate the optics configuration for beam extraction to the two different target destinations.

Figures 3-5 and 3-6 depict the beam spots for target A and B, respectively, which were calculated using the software TURTLE [2]. Table 3-2 summarizes the calculated parameters for the spot sizes on the two targets as well as the corresponding beam size on the primary dump.

Table 3-1: Multi-target configuration of the two north targets. The position of the target heads as seen in beam direction is depicted on the right side.

Head	Material	Length (mm)	Diameter (mm)	Comments
1	Be	200	10 + Al case	Electron enriched
	W	3		
2	Al	100	10	Electron enriched
	W	3		
3	Al	200	10	Hadron
4	Air	-	-	Empty
5	Al	20	10	Hadron



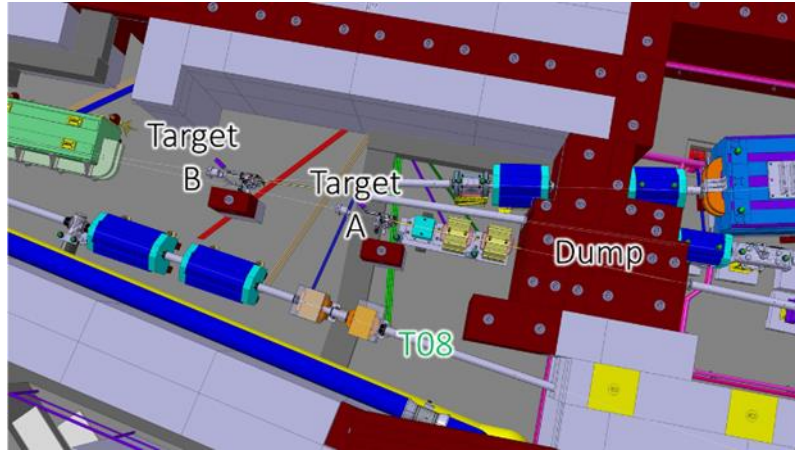


Fig. 3-2: Layout of the target region around the production targets for the T09 secondary beamline (target A) and for the T10/T11 beamlines (target B).

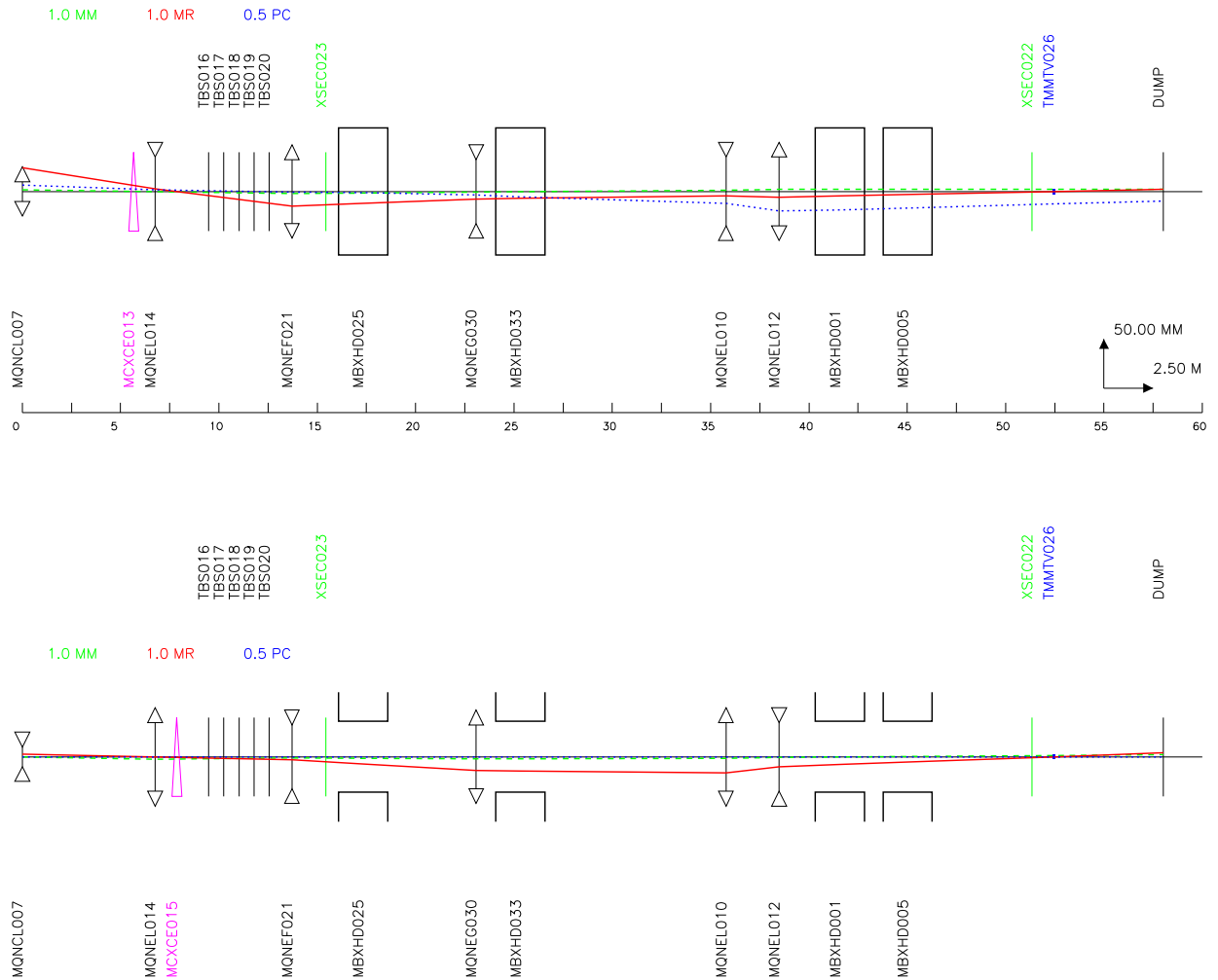


Fig. 3-3: Optics for the primary proton beam in F61/F62 from the PS extraction to target A as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

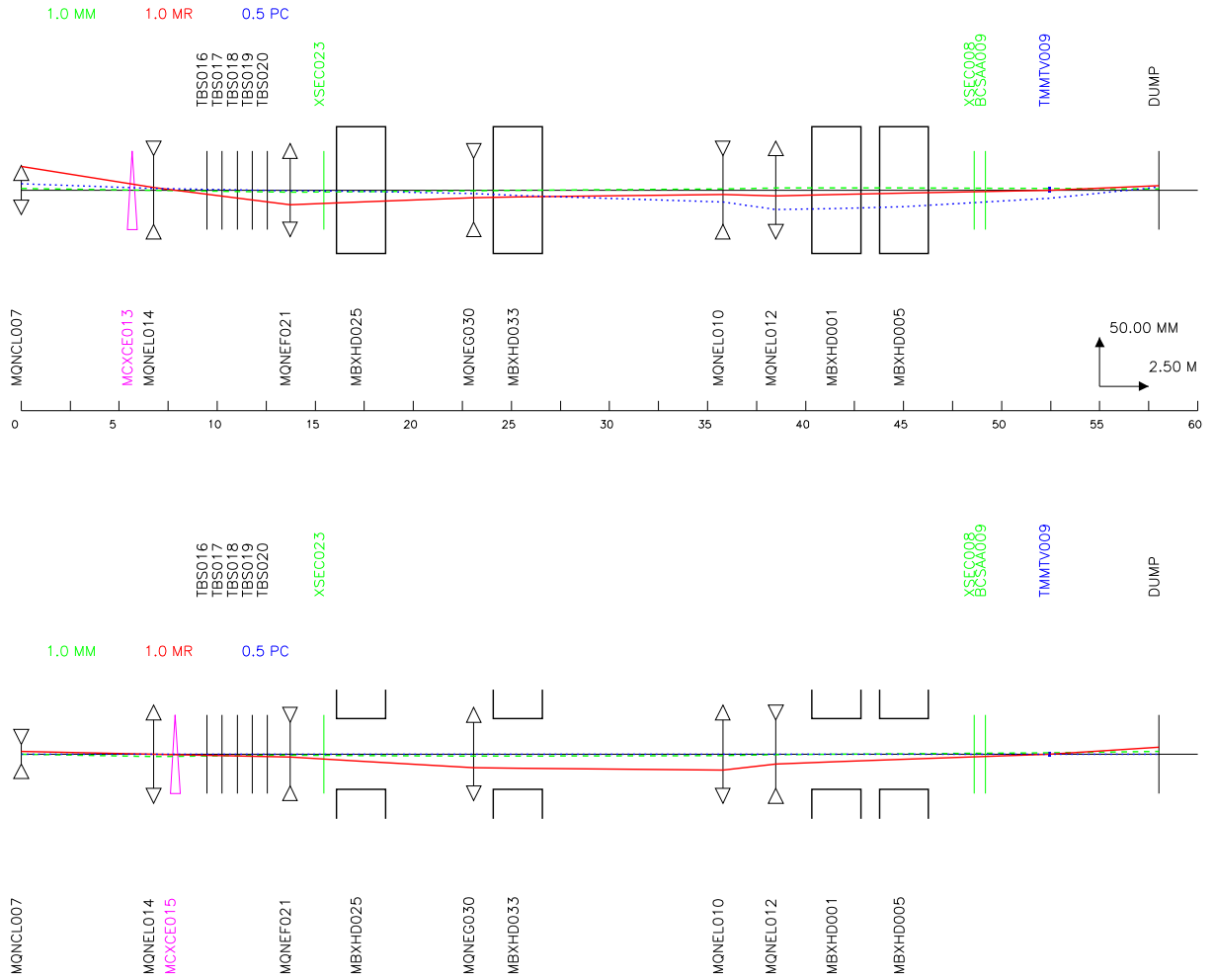


Fig. 3-4: Optics for the primary proton beam in F61/F62 from the PS extraction to target B as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

Table 3-2: Calculated beam spot parameters for the two targets A and B as well as the corresponding size of the beam when it enters the primary dump for destination A and B. For better comparability, the values are given in terms of the standard deviation σ and 4σ that were found by fitting a Gaussian model to the results of TURTLE raytracing.

Location	Plane	σ (mm)	4σ (mm)
Target A	Horizontal	1.7	6.9
	Vertical	0.7	2.8
Target B	Horizontal	1.3	5.3
	Vertical	0.6	2.5
Dump for A	Horizontal	1.7	7.0
	Vertical	1.1	4.4
Dump for B	Horizontal	0.9	3.7
	Vertical	1.3	5.2

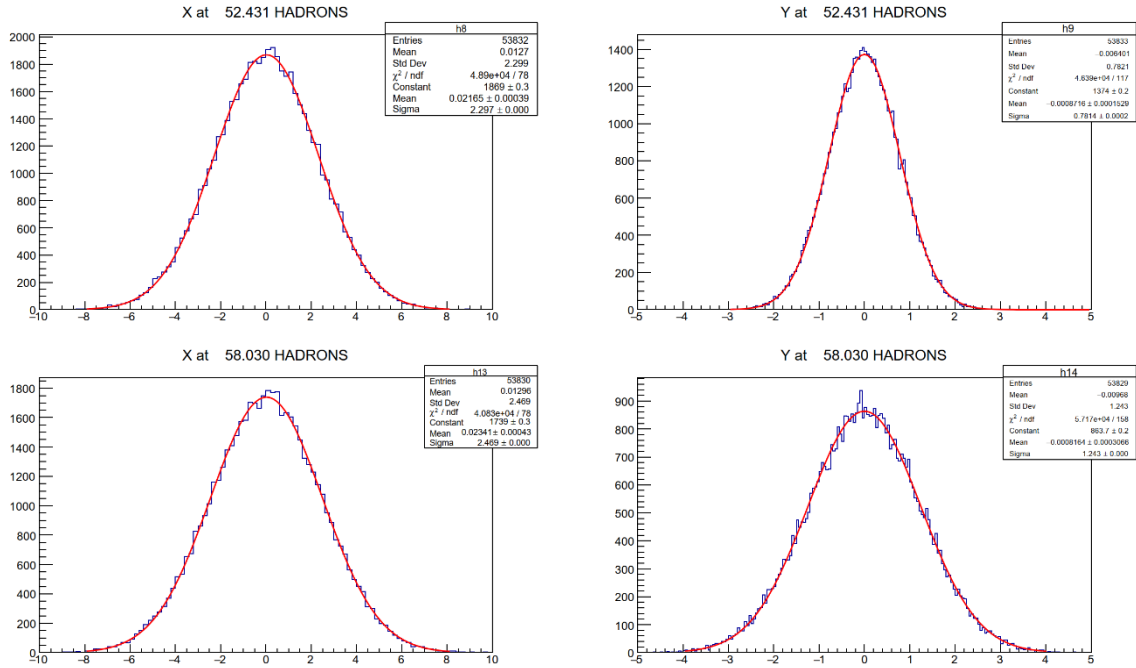


Fig. 3-5: Calculated beam spot parameters for target A (upper panels) and the corresponding spot size on the primary dump (lower panels). The left side shows the horizontal plane while the right side shows the vertical one.

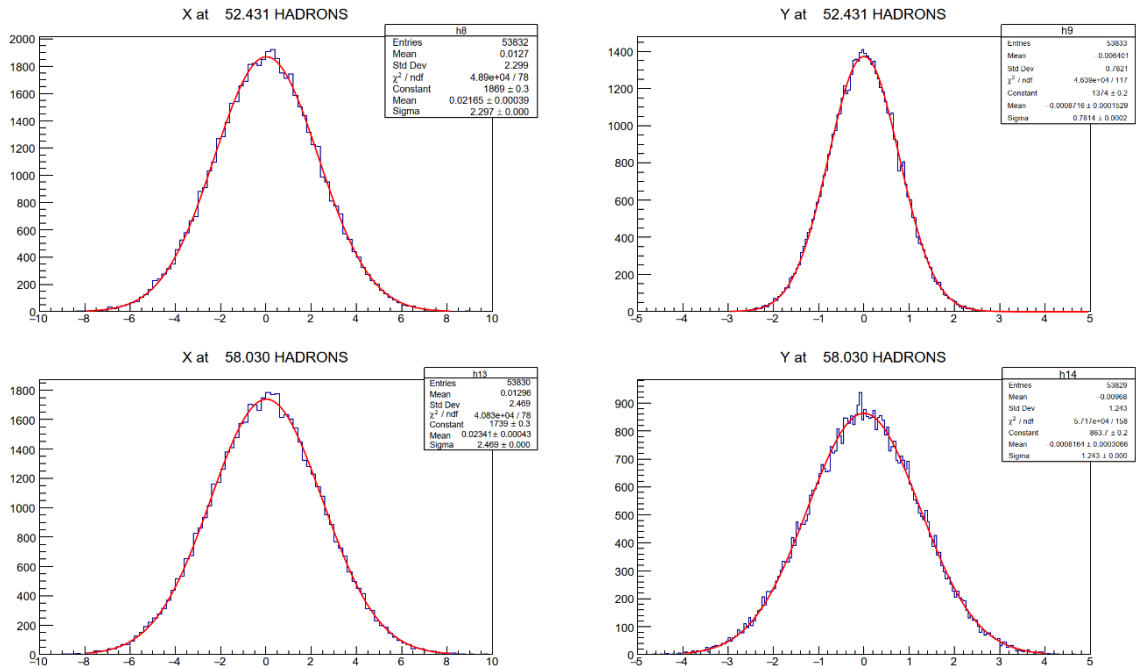


Fig. 3-6: Calculated beam spot parameters for target B (upper panels) and the corresponding spot size on the primary dump (lower panels). The left side shows the horizontal plane while the right side shows the vertical one.

3.1.4 The primary beamline T08

The primary beamline T08 serves the irradiation facilities IRRAD and CHARM. Both experimental areas were completely redone during LS1 in addition to changes in the T08 line, which are detailed in Ref. [2].

The aim of the currently discussed redesign of T08 is to keep both experimental areas unchanged, while matching the line to the newly designed primary zones at the change-over point F61.BHZ02. Furthermore, the T08 beamline has been cleared of leftover magnets due to the old T07 line and magnets have been exchanged with similar laminated models in order to respect the new pulsed powering scheme.

After passing F61.MBXDH033, the beam is bent away from the location of the north targets by an MCB-type dipole magnet and matched with the help of a first doublet of quadrupoles. Then, the beam is bent in direction of the experimental areas by a pair of MCB-type dipoles. The final focus consists of a pair of Q200 quadrupoles that allow focussing of the beam on each IRRAD experimental table, as well as on the CHARM production target. Figure 3-7 depicts the optics as an example for T08 for a focus on the second IRRAD table. Steering of the beam as well as correction of a possible angular mismatch between F61 and the T08 line are possible after introducing two sets of MDXL corrector magnets for both horizontal and vertical corrections. These magnets can also be used to shift the beam position parallel to any direction in order to cope with possible alignment mismatches of irradiation samples. In addition, a programmable function generator on the power supply of these correctors allows a sweeping of the beam on the user samples if required.

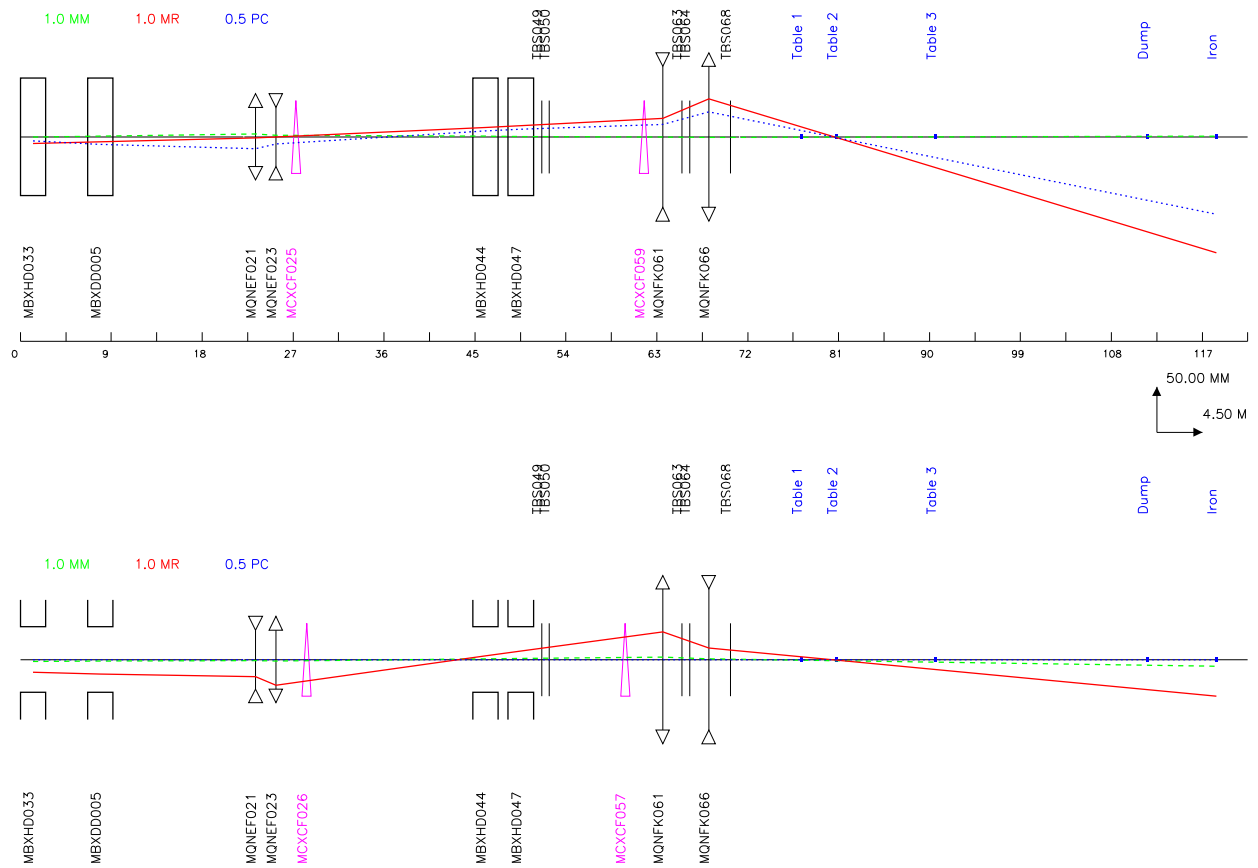


Fig. 3-7: Optics for the primary proton beam in T8 from F61.BHZ02 to the irradiation facilities IRRAD and CHARM as calculated with TRANSPORT, here exemplary for a focus on the second IRRAD table. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

For access purposes and as safety elements, five beam stoppers have been included in the beamline, analogue to the beam stoppers in F61.

3.1.5 Summary of beam parameters, primary destinations, and operational considerations

The main beam parameters of the primary proton beam are listed in Table 3-3. The synoptics of destinations of the new East Area is presented in Fig. 3-8 in comparison to the old scheme. Apart from the change of using two production targets, the destination F6D has been included, for which the beam is dumped on the operational dump that will be used for set-up of the PS extraction. The old destinations DIRAC, T07, and IRRAD (old) have been already removed in LS1.

All primary lines, including T08, can be operated within the 2.4 s extraction cycles of the PS. Due to limitations in the cycled powering of large dipoles in the secondary beams, these beams can only be operated in 4.8 s cycles. Still, alternating the primary beam on the targets every 2.4 s is possible, as long as the same target destination is not programmed twice in a row. Including radioprotection constraints as well, the maximum number of T08 cycles should not exceed six per typical 45.6 s SPS super-cycle and the maximum number of cycles per target destination shall not be more than three. The total instantaneous intensity in the East Area shall not exceed 6.7×10^{10} protons per second. Assuming 90% efficiency and a maximum number of 340 000 super-cycles per year, this would limit the integrated yearly intensity of protons to 10^{18} .

Table 3-3: Main parameters of the primary beam.

Parameter	Value
Proton beam momentum [GeV/c]	24
Maximum # spills per typical super-cycle	6
Duration of typical super-cycle [s]	45.6
Maximum # protons per second	6.7×10^{10}
Maximum assumed number of days of operation per year	200
Assumed efficiency	90%
Maximum number of super-cycles per year	340 000
Maximum number of protons per year	1.0×10^{18}

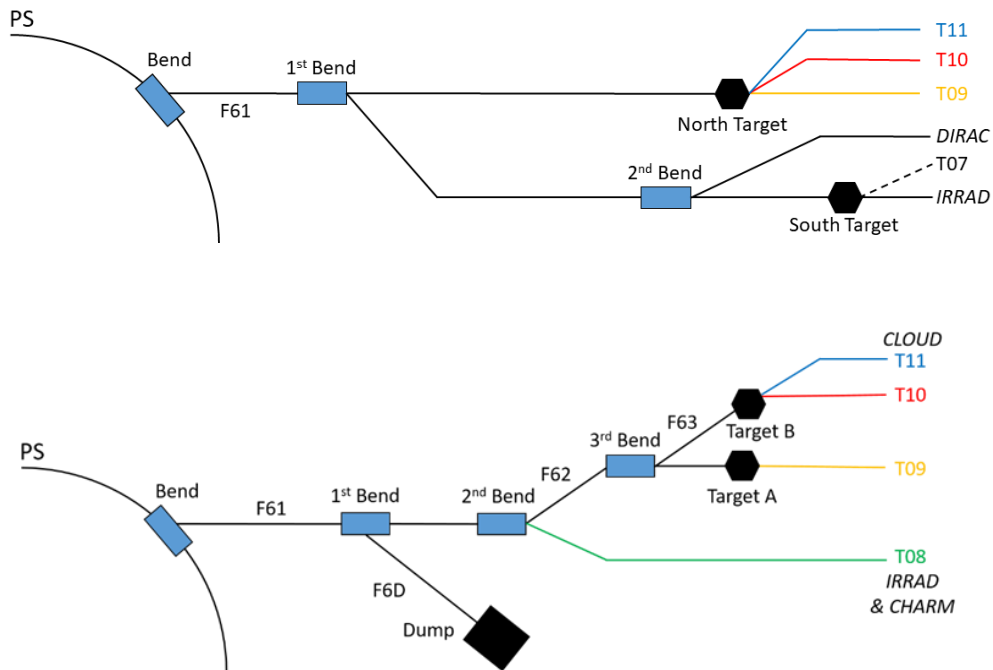


Fig. 3-8: Synoptics of the old East Area (upper panel) in comparison to the new East Area (lower panel).

3.1.6 The secondary beamlines T09 and T10

Both beamlines are based on the same concepts of secondary beams, based in the operational experience of the West Area beamlines. Hence, both beams will be discussed at the same time while differences will be highlighted when they occur. The general design aims at providing secondary beams with high selectivity of particle species, i.e. purity. In addition, the aim was to optimize for high acceptance and momentum resolution.

The beams are derived from the targets A and B under a vertical production angle in order to prevent primary protons coming into the experimental areas. The production angles were chosen to be 30 mrad (T09) and 35 mrad (T10) in order to reach the same height in the experimental areas due to the different total lengths of the beamlines. In T09, a fixed collimator (XTCX) with a cylindrical aperture of 80 mm diameter defines the initial angular acceptance and acts at the same time as passive machine protection for the magnetic elements that follow. For T10, such a dedicated fixed collimator was not deemed necessary as the beam is defined well by the primary beam dump aperture and because no equipment upstream of the dump would need protection. The non-interacting primary protons are dumped in the primary dump, while secondary particles are allowed to pass through pre-defined apertures towards T09, T10, and T11 (see also the next section). In T09, a set of two horizontally deflecting MDXL correctors can optionally be used as sweeping magnets to dump also charged secondary particles, effectively leaving only a secondary neutral beam. Just after the primary dump, a movable lead foil of 4 mm thickness can be employed to convert photons to electrons and positrons via pair production. In this mode, electron and positron beams with high purity can be reached. This option was unfortunately not possible for the T10 beam due to space and integration constraints related to the presence of the T11 line. Nevertheless, this could be a valuable future upgrade option.

The frontends of T09 and T10 consist of a triplet of quadrupoles (QFO1¹, QDE2, and QFO3) that are used to focus the secondary beam onto a horizontal collimator, COLL 3, which defines the central momentum together with the initial horizontal deflection of BHZ1 (M200L dipole). In addition to COLL3, another set of lead foils with three different thicknesses (4 mm, 8 mm, 26 mm) can be used as an absorber to filter out of the beam a certain fraction of electrons respectively positrons (50%, 75%, 99%), leaving a hadron beam of selectable purity. In between the second and third quadrupole, two collimators, COLL 1V and COLL 2H, define the vertical and horizontal acceptance of the beamline, respectively. A second horizontal M200L dipole magnet (BHZ02) is used to deflect the beam towards the respective experimental areas. Around the central collimator COLL3, two quadrupoles are used as field lenses, with the aim of eliminating the dispersion after BHZ2. The final focus consists of a triplet of quadrupoles (QDE6, QFO7, and QDE8), which focus the beam at the user location. In T10, the last quadrupole is of type Q100L in contrast to T09, where a Q200L is necessary due to the higher maximum momenta. In order to compensate the production angle of the target, a vertical M100L magnet deflects the beam with the aim of making it parallel to the horizontal floor of the experimental area. This magnet serves at the same time as a vertical corrector if necessary. For horizontal steering, a MDXL corrector can be used. For access purposes, a dedicated, movable stopper-dump exists. This dump can be also used as an effective filter for hadrons and electrons/positrons leaving muon beams of high purity, which can be optionally momentum selected with the help of BHZ02. Alternatively, the first collimator can be closed off axis to select a similarly pure muon beam.

The maximum beam momentum in T09 is 15 GeV/c and for T10 is 12 GeV/c. They differ mainly due to the larger deflection angles in T10 that are necessary to deflect the beam away from T09 as well as to compensate for the shorter length of the T10 line. Table 3-4 summarizes the calculated beam parameters for both beamlines. In addition, the T09 parameters are compared to the values of the old T09 line. Figure 3-9 depicts the optics exemplary for T09.

¹ Due to the different equipment names, but similar functions, the physics name for the beamline elements is used in this descriptive part.

Table 3-4: Beam parameters for the future T09 and T10 beamlines. For convenience, a comparison to the old T09 values is given in addition.

Parameter	T09 (old)	T09 (new)	T10 (new)
Length up to the last element [m]	54.3	50.2	44.7
Max. momentum [GeV/c]	10	15	12
Momentum resolution	0.7 %	0.5 %	0.5 %
Max. momentum band		± 15 %	± 15 %
Horizontal acceptance	± 4.8	± 4	± 5
Vertical acceptance	± 4	± 3.8	± 3
Horizontal magnification at final focus	0.81	0.86	0.92
Vertical magnification at final focus	0.91	0.9	0.58
Max. flux per spill	10^6	10^6	10^6

3.1.6.1 Future options

In the baseline of the East Area Renovation, there are no spectrometer magnets in the T09 and T10 experimental areas, which might be a sensible future upgrade. Adding a converter and sweeping magnets in T10 would allow for high purity electron and positron beams as for T09. However, current space restrictions, especially due to the T11 beamline, do not permit this option at the moment. Figure 3-9 shows the optics for the secondary T09 beamline from target A to the endpoint/dump of the experimental area.

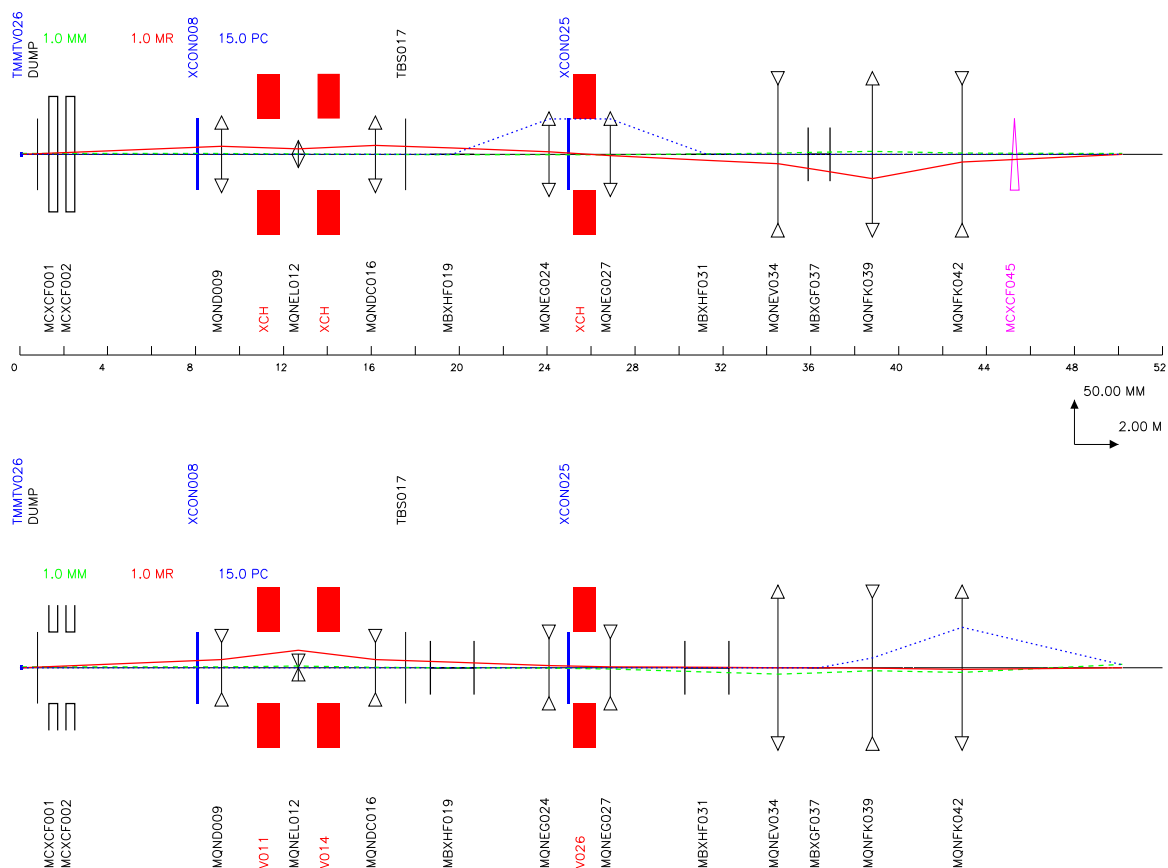


Fig. 3-9: Optics for the secondary T09 beamline from target A to the endpoint/dump of the experimental area as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

3.1.7 The secondary beamline T11 for the CLOUD experiment

The T11 beamline employs the same principles as T09 and T10, however, in a more compact form and with less elements due to the constraints of leaving the CLOUD experiment at the same place (see Fig. 3-10). The beamline shares the production target B with T10 and the initial acceptance is well defined by the primary dump aperture. The frontend and the final focus are doublets of quadrupoles in contrast to T09 and T10, where more flexibility is required. Another difference is to use only one field lens quadrupole and collimators with less control in both planes. In addition, the vertical M100L dipole was removed as it is not necessary for CLOUD. There are also no correctors in this beamline. The beam optics are chosen to provide a large spot on the CLOUD experiment by over-focusing the beam directly after the last quadrupole and hence the beam opens up again due to the large divergence.

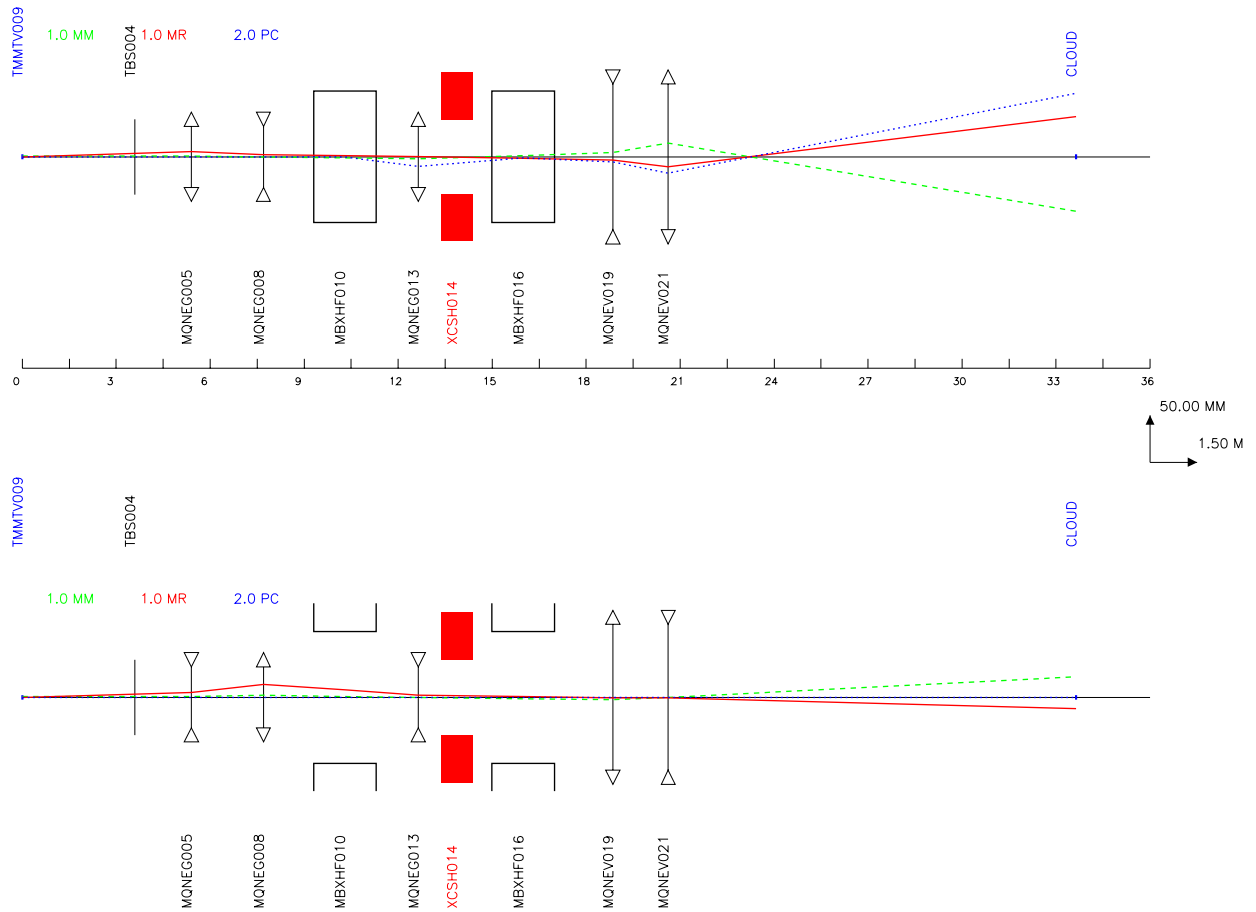


Fig. 3-10: Optics for the secondary T11 beamline from target B to the endpoint/dump of the experimental area of CLOUD as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane. The new layout of the East Experimental Area.

3.1.8 Introduction

The implementation of the new beamlines (see Section 3.1) and the application of modern safety standards (see Section 3.3) justify a major re-organization of the Building 157 hall. By extension, the proton synchrotron (PS) extraction beamline located in Building 352 has also been completely renovated. In addition, the new powering scheme of the magnets allows suppression of the need for Building 263 to host the power converters but required a major renovation of Building 251 to accommodate all of them (see Section 4.2).

Figures 3-12 and 3-13 show, respectively, the configuration of the East Experimental Area before and after renovation. Building 352 hosts the extraction line from the PS. In this area, until the wall separation with Building 157, the lines F61, F62, F6D, and the first part of the line T08 will be installed. Building 157 hosts instead the F63 line, the following parts of the T08 line, T09 T10, and T11 beamlines, and the experimental areas.

Building 157 is sub-divided into different areas. Right after the wall separation with Building 352 the *primary area* is installed; this area is further divided into three closed areas: the *target area*, the *T08b area*, and the *T08c area*. The T08 line finishes with the *IRRAD/CHARM (proton IRRADiation facility/CERN High energy AcceleRator Mixed field facility)* area that was installed during Long Shutdown 1 and will not be affected by the renovation. After the target area, the protons enter the *mixed area*, where the secondary lines start to separate. The T11 line, after the mixed area, directly enters the *T11 experimental area* hosting the Cosmic Leaving Outdoor Droplets (CLOUD) experiment. On the other side, the T09 and T10 lines share a second closed area called the *T09-10 area* before entering in the separate *T09 and T10 experimental areas*.

3.1.9 Building 352: PS extraction

The renovation in Building 352 consists mainly in installing the new F61, F62, F6D beamlines and the beginning of T08 (see Section 3.1). Moreover, services like Direct Current (DC) cabling (see Section 5.6) and the cooling network (see Section 5.2) will be renovated. In addition, F61 and T08 beamlines will be equipped with new PS standard beam stoppers (see Section 4.4) and new beam loss monitors (see Section 4.5). Figure 3-11 depicts the new layout for Building 352.

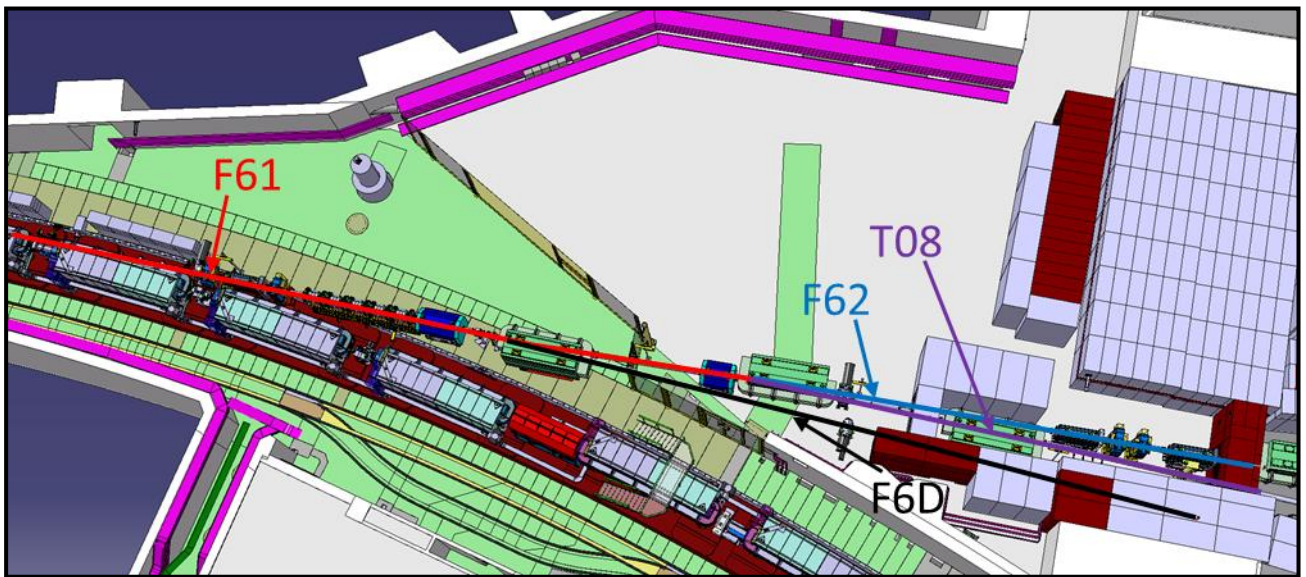


Fig. 3-11: Three-dimensional model of Building 352 after renovation.

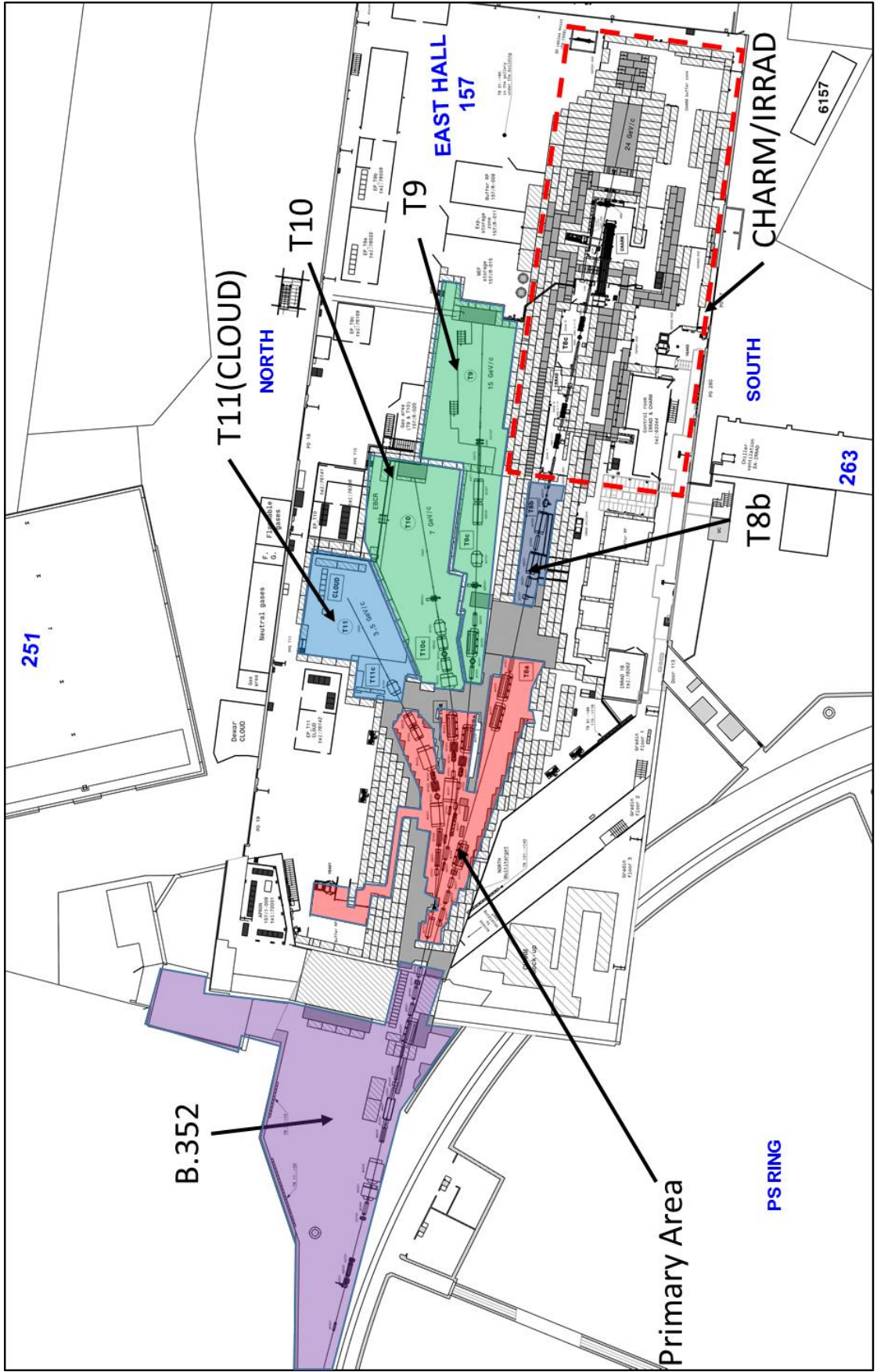


Fig. 3-12: Configuration of the East Area before renovation.

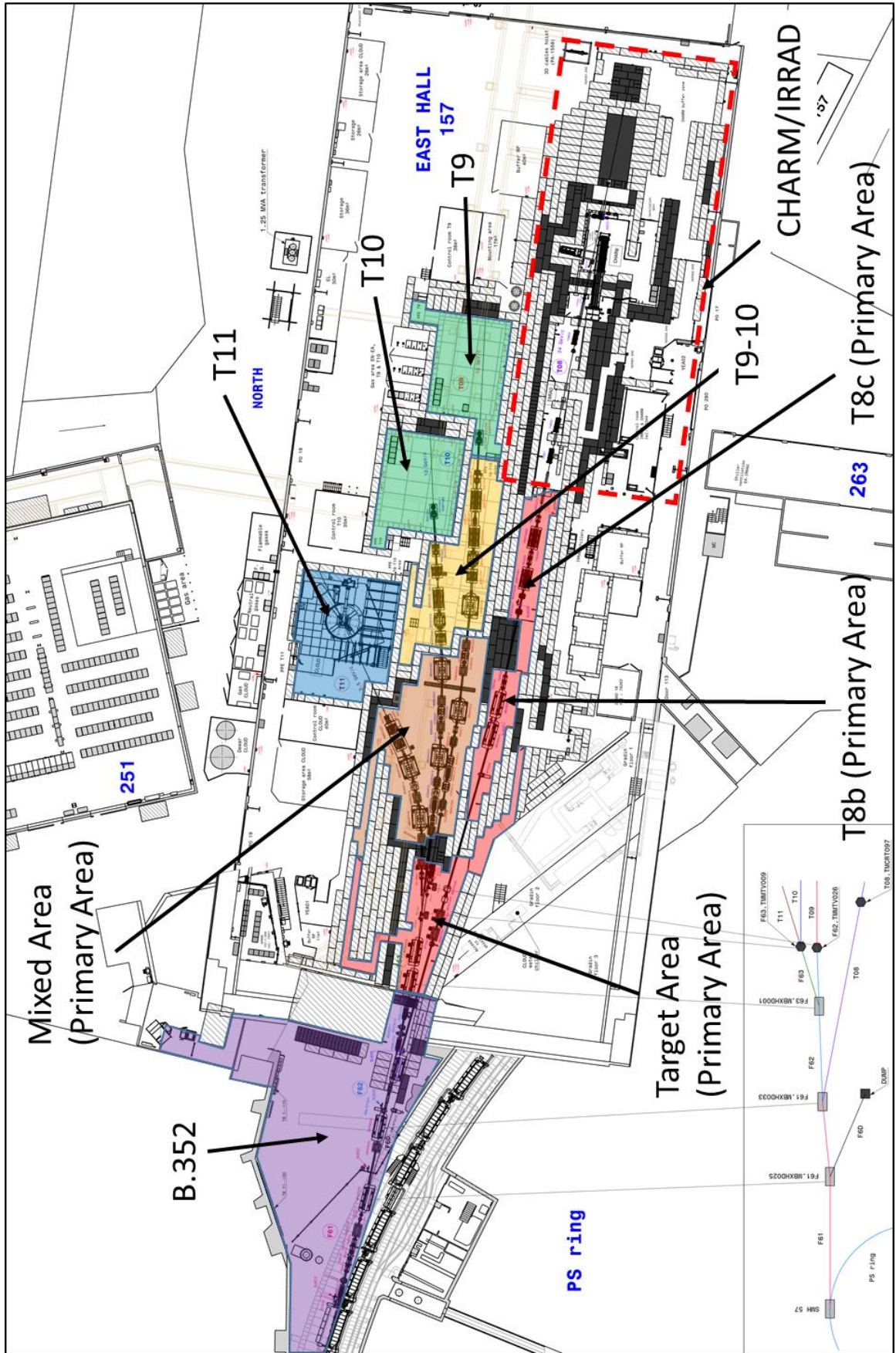


Fig. 3-13: Configuration of the East Area after renovation.

3.1.10 Building 157: Experimental facility

3.1.10.1 Primary area

The goal of the new layout of the primary area after renovation is to improve the general safety, in particular to minimize the radiation levels in each controlled area. For this reason, the target area has been reduced thanks to a new cast iron dump located in between the target area and the mixed area, which stops the residual primary particles coming from the interaction of the PS protons beam with the targets. All the primary areas will be airtight, and a dedicated ventilation system will keep the internal pressure of the primary areas lower than the atmospheric external pressure, so that any contaminated agents are kept inside the area (see Section 5.4).

The primary area is composed of three sectors: the target area, T08b, and T08c (see Fig. 3-14 and Fig. 3-15). These, in particular the targets area, will be the most radioactive zones in the East Area, due to the interactions of the PS primary beams with the two targets. Due to the high level of radiation, a shielding roof in concrete and cast iron is required, and the total height of the whole shielding will be limited to 8 m (height of the overhead cranes).

Inside the target area, magnets, targets, the fixed collimator (XTCX), and the stopper dump will be equipped with a mechanical plug-in support to suppress the need for alignment in situ when the replacement of an equipment is needed [2]. Although alignment is the most time-consuming task in this area, it will greatly reduce the exposure of workers to radiation.

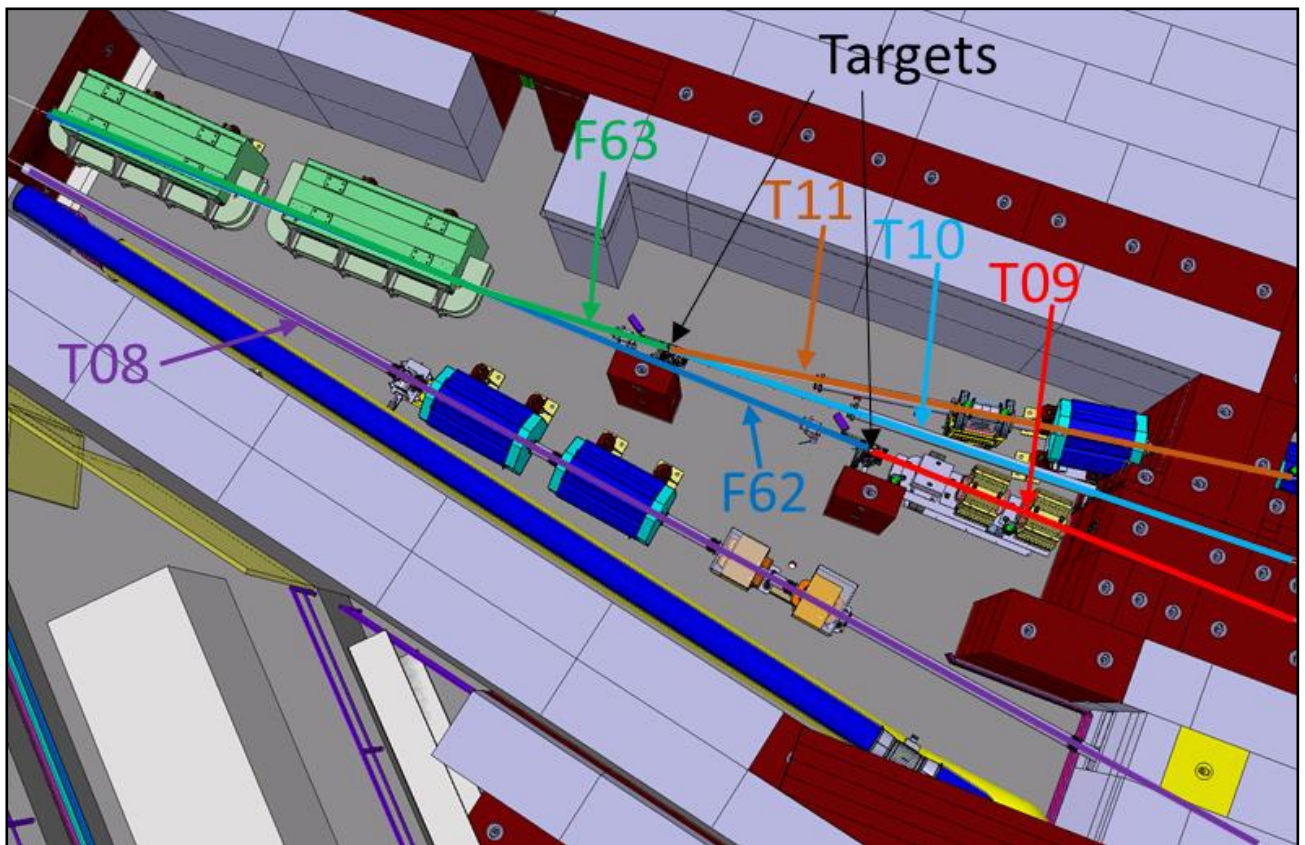


Fig. 3-14: Integration 3D model of targets area.

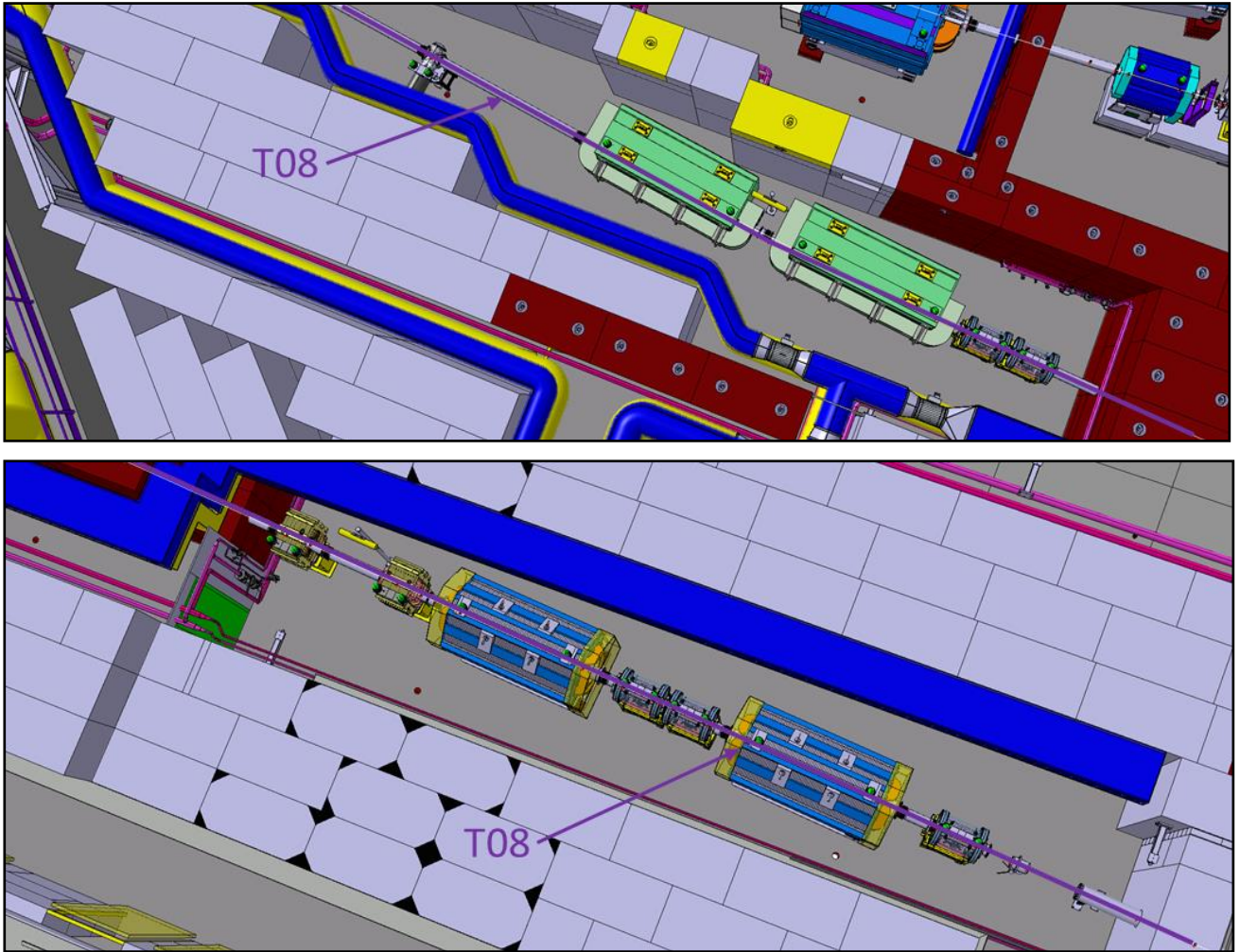


Fig. 3-15: T08b (top) and T08c (bottom) primary areas.

3.1.10.2 Mixed area

This new zone (see Fig. 3-16) is just downstream of the target area and it hosts the three secondary beams (T09, T10, and T11). Because there is a low radiation level in this area, a thinner concrete shielding roof is sufficient for safety protection. All the equipment is integrated on standard supports. The expected residual radiation dose rate does not justify the installation of a plug-in system. All the secondary beamlines have a vertical angle (production angle) in this area.

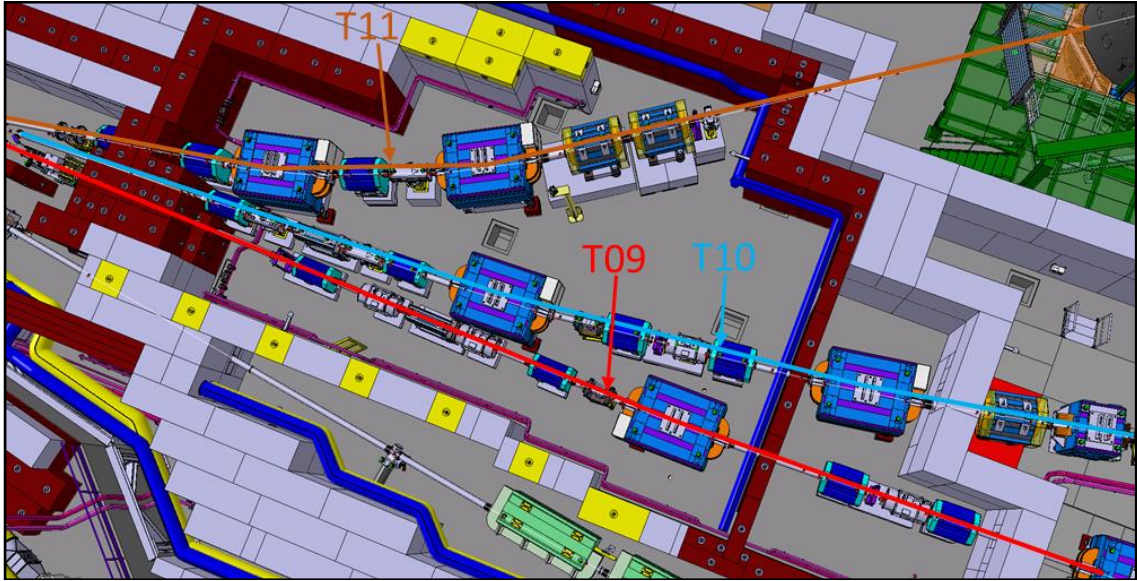


Fig. 3-16: Mixed area after renovation.

3.1.10.3 T09-10 area

This new zone is located just downstream of the mixed area and contains the last magnets and other equipment of the secondary beamlines, as illustrated in Fig. 3-17. The benefit of creating this zone in both T09 and T10 experimental areas is that the users of the experimental areas will not be in proximity to the beamline equipment, reducing personal electrical shock risks. In addition, maintenance in this area can be done while the beam is circulating in the T08 and T11 beamlines.

The T09-10 area does not require roof shielding, thanks to the low radiation levels. The floor of this zone is fully covered with 1.2 m standard concrete blocks to compensate for the beam height (around 3 m from the floor of the building). The vacuum pumps for the T09 and T10 beamlines are placed in this area to limit exposure to radiation of the maintenance teams.



Fig. 3-17: T09-10 area.

3.1.10.4 Experimental areas: T09, T10, and T11 (CLOUD)

The T09 and T10 experimental areas are designed as general-purpose test zones. The new layout of the experimental areas takes advantage of strong experience from past operation (see Fig. 3-18). Consequentially, the design of this layout focuses on the safety and convenience of the users.

The major improvements in the T09 and T10 experimental areas are the following.

- i) Same beam height in T09 and T10.
- ii) Separation between users and machine services (cables, gas piping).
- iii) Quantity and type (16 A, 32 A) of power sockets increased.
- iv) New standard signal cable patch panels between the experimental areas and the control room.
- v) New racks for a gas patch panel inside T09 and T10.

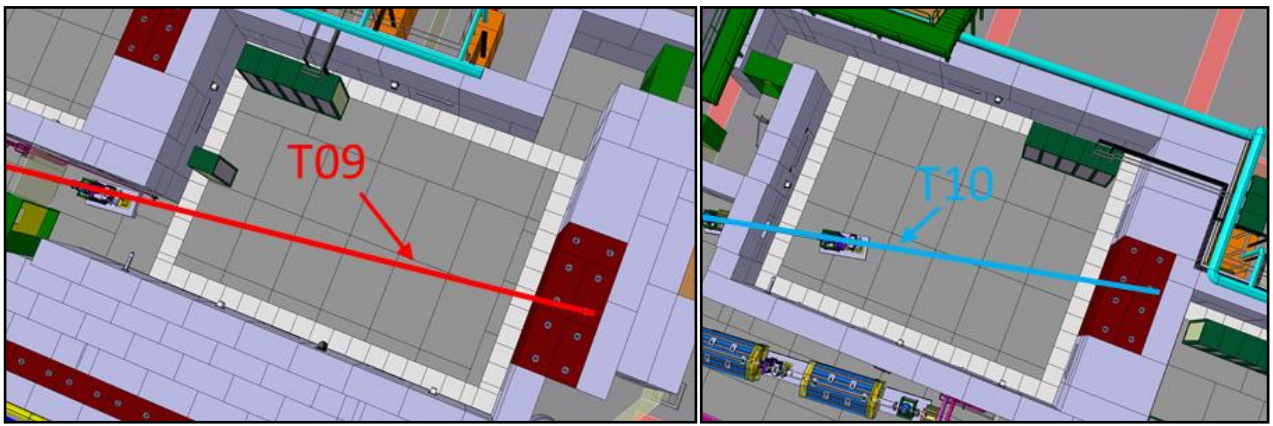


Fig. 3-18: T09 (left-hand side) and T10 (right-hand side) experimental areas.

The T11 experimental area (Fig. 3-19) will continue to host the CLOUD experiment. In addition, this area will profit from the enhancements of the renovation project in the following aspects.

- i) Increase of the surface of the experimental area (layout of the platforms upgraded accordingly).
- ii) The CLOUD storage area will be moved closer to its control room.
- iii) The chiller used by the experiment will be relocated on the other side of Building 157 to suppress the noise disturbance.

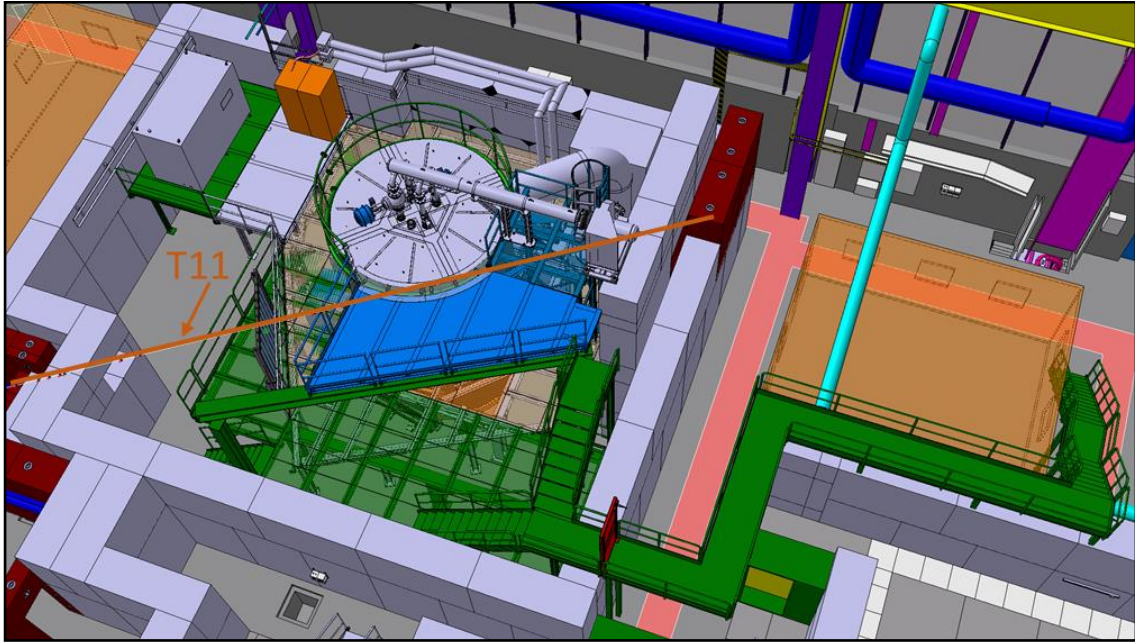


Fig. 3-19: T11 experimental area hosting the CLOUD experiment.

3.1.11 Building 251: Power converter facility

Building 251, which hosts all the power converters, will be renovated to accommodate the new configuration and requirements of the future beamlines.

The existing power converters have become less reliable and will be replaced by different types of modern SIRIUS power converters, including SIRIUS S, 2P, 4P, and 4P + (see Section 4.2). Since these new power converters have different characteristics (weight, size) compared to the old ones, the structures on which these converters are installed, the electrical supply system, and the cooling system must be redone during the renovation (see details in Fig. 3-20 and Fig. 3-21).

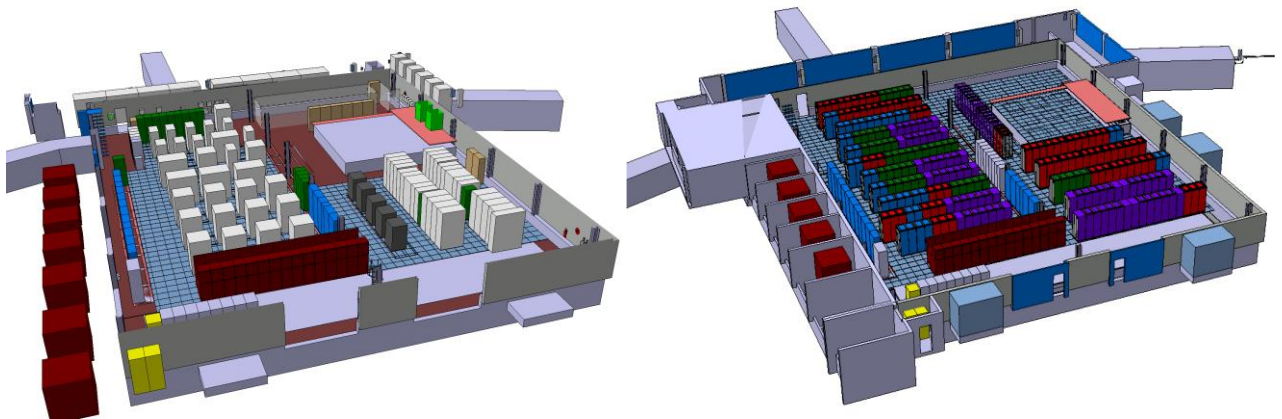


Fig. 3-20: Configuration of Building 251 before (left) and after (right) renovation.

Furthermore, the poor state of the existing false floor and the difficulty of accommodating all the new power converters and services, led to the decision to instal a new false floor in the building. The concept for the new layout of Building 251 can be found in Fig. 3-21.

In particular, the following actions will take place during the renovation in LS2.

- i) Renewal of the false floor to support all the power converters.
- ii) New cooling network and ventilation dedicated to the power converters.

- iii) Renewal of the electrical infrastructure to provide AC current to the power converters.
- iv) Re-organization of the DC cabling to connect the power converters to magnets in Building 157.

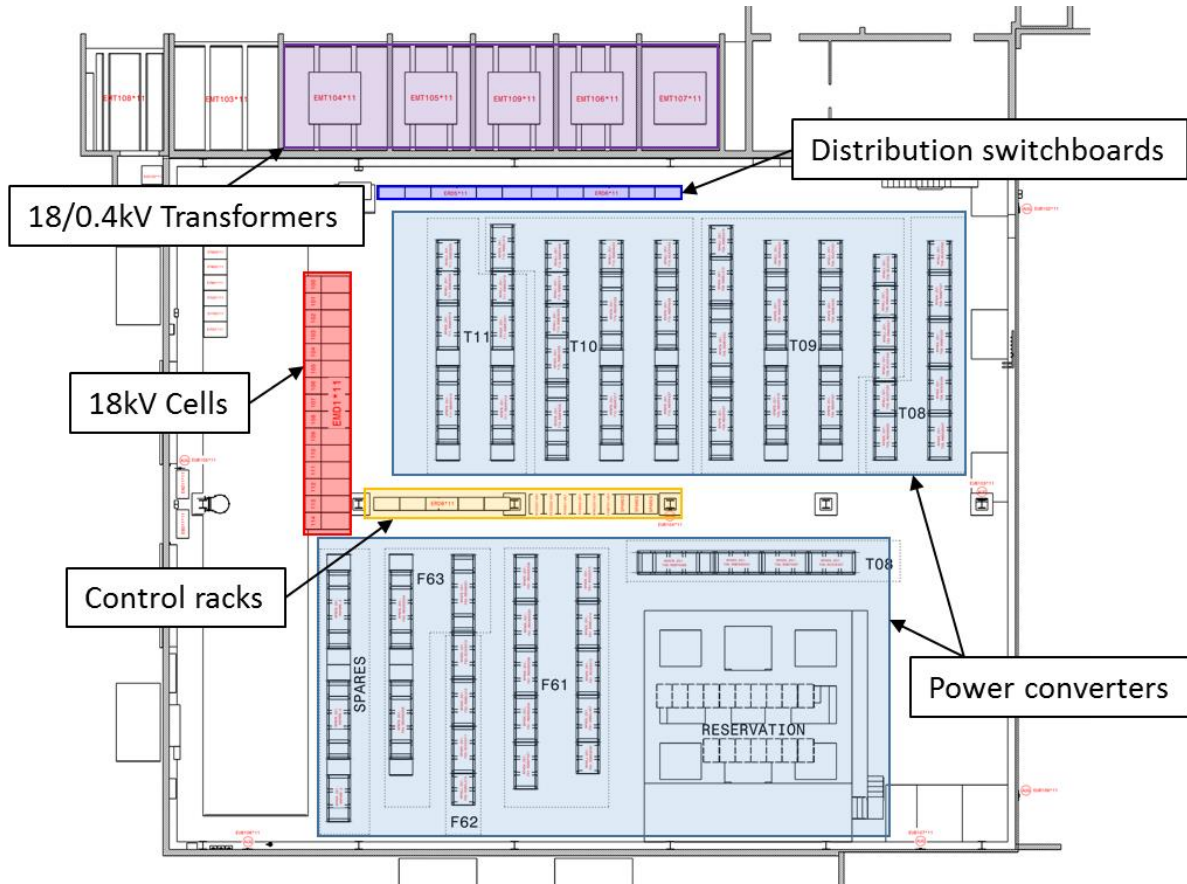


Fig. 3-21: Future layout of Building 251.

3.2 Energy savings

One of the objectives of the East Area Renovation Project is to reduce the energy consumption of the facility. This section summarizes the various measures taken to achieve an operational experimental facility with low energy consumption.

3.2.1 The magnet power supply chain

The most substantial change induced by the renovation in terms of energy will be the modification of the powering mode of the magnets. The new power converters, of type SIRIUS, conceived at CERN by the Electrical Power Converters Group, will be able to operate the new laminated magnets in pulsed mode. Equipped with capacitor banks, the SIRIUS converters will also be able to recover temporarily the inductive energy stored in the magnetic field of the magnetic components, as shown in Fig. 3-22 and reuse it for the next cycle. Those recovering units reduce the root mean square (RMS) current requirements of equipment upstream of the electrical supply network and eliminate the voltage fluctuation of the CERN general electric grid, thus simplifying it and decreasing the losses.

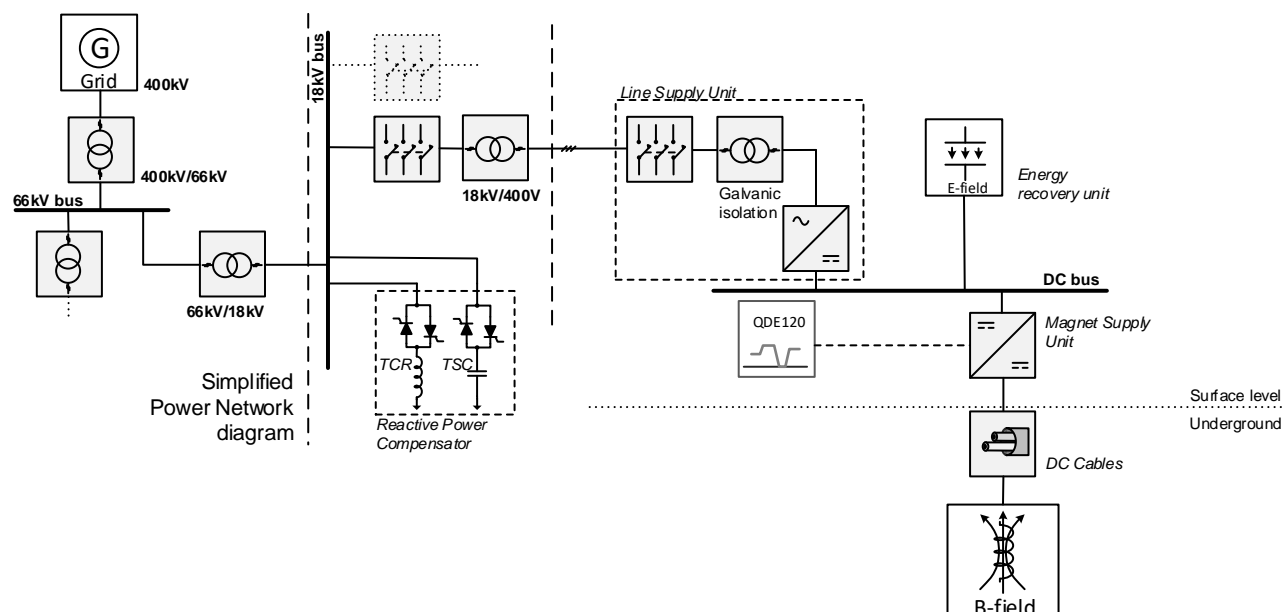


Fig. 3-22: Overview of the magnet power supply chain.

Today, the magnets are turned on at the start of the physics run and, if no major issue occurs, are never turned off, even when no beams are being extracted towards the East Area. Bearing in mind that the beamlines today count 54 magnets, which in theory only need to be generating a magnetic field for 2.25 seconds (which equals to 5 extractions) per supercycle², significant energy saving can result from a compatible magnet and powering scheme. Such a cycled mode gives the opportunity to only feed the required magnets to extract and direct the particles towards one of the four experiments.

Furthermore, a lower electricity consumption will significantly decrease the power losses and thus the related dissipated heat, having consequently also a direct influence on the energy consumption needs for the water cooling and air ventilation systems and therefore on their installation and operational units.

Even though it is impossible to predict the number of extractions occurring in a future physics run, an estimated electricity consumption can be calculated based on the number of extractions which took place in 2017. Based on retrieved current data of the 2017 physics run, the electricity usage before renovation (6786 MWh) was calculated. Compared to the estimated consumption in cycled mode (1028 MWh), a potential saving of more than 80% can be demonstrated.

In addition, while power converters still consume electricity in maintaining stand-by mode, a future remote control by the operators allows us to completely switch-off the equipment during long periods of inactivity.

3.2.2 Air ventilation

Currently, air ventilation systems are present in the main experimental hall and the irradiation facilities³ on beamline T8, ensuring thermal comfort and an adequate air quality inside the hall as well as a dynamic confinement (preventing the activated air from escaping) for the highly radioactive areas. Building 251, adjacent to the Building 157 hall and housing the power converters, is also equipped with a heating and

² The supercycle of the PS accelerator lasts for 45.6 seconds and depicts the distribution of the particle bunches from the accelerator towards the related experiments (nTof, AD, IRRAD, CHARM, ...) and the Super Proton Synchrotron accelerator.

³ Highly radioactive areas are covered with thick (up to 6 metre) concrete walls allowing for the presence of the users inside the hall during beam operation.

ventilation system providing heating during winter and fresh air ventilation that partly removes the heat dissipated from the converters during warmer periods.

The air ventilation's energy consumption in the experimental hall is mainly due to the heating needs during cold months. During the hotter months, the heating is turned off and thermal comfort is uniquely assured by ventilation. Heating in the East Area and at CERN in general is provided by a central plant producing, by means of gas combustion, super-heated water (SHW) which is distributed to the concerned infrastructures located on the various CERN premises.

The cladding of the main hall is currently far from optimal when compared to today's environmental and safety standards, causing over the year an increase in air ventilation needs. Civil engineering works have therefore been included in the project. By refurbishing the cladding and the roofing with more modern and better performing insulated materials, associated thermal losses significantly decrease.

Detailed thermal studies of today's and the post-renovation situation have been conducted [4]. From this study, the following results have been found; the peak losses occurring during the coldest month (January) will drop from 811 kW to 245 kW, the annual thermal energy consumption will decrease by 65% together with a 65% decrease of the related gas consumption.

The project also includes a modification in the disposition of the radioactive areas, similar to the one performed for IRRAD/CHARM in LS1. Thus, introducing new specific air handling units to the primary [5] and a new ventilation system to the mixed beam area (see Fig. 3-23), leads to a total of three dedicated ventilation systems for those areas. In addition, to ensure a dynamic confinement, they compensate the dissipated heat from the magnets, which will decrease due to the above described cycled operation mode. Related thermal energy savings will amount to 75%. However, at the same time, the electricity consumption for the primary areas must cover an increase of 42% (from 11 MWh to 19 MWh) due to the required additional units.

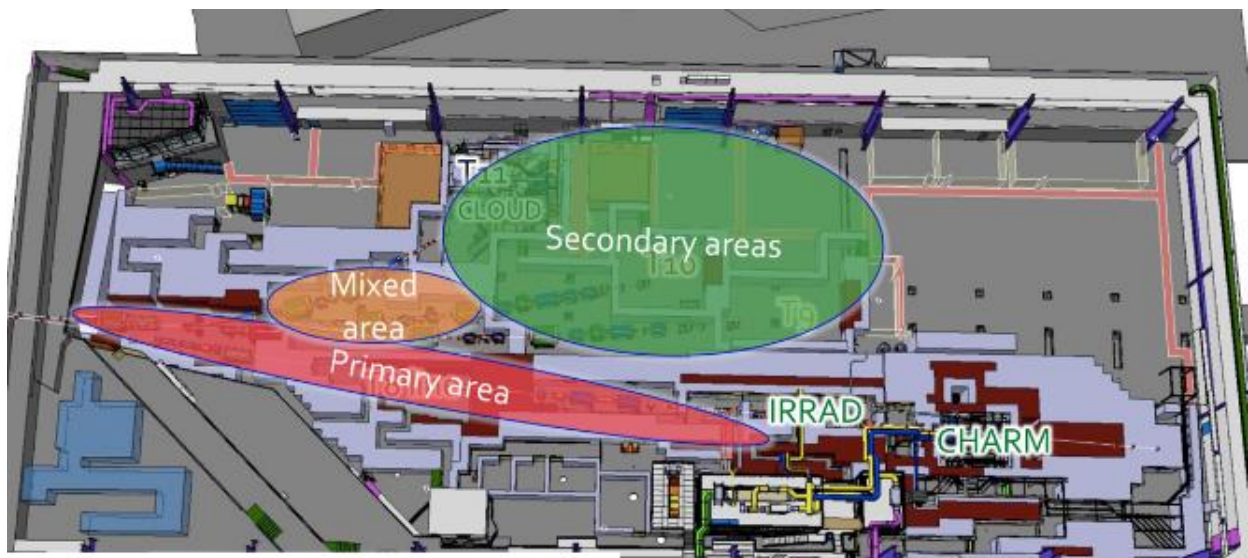


Fig. 3-23: Layout of the new radioactive zones.

Finally, the power converter building will see a 96% reduction in cooling needs (from 955 to 63 MWh). The substantial decrease is related to the fact that the new power converters will be water cooled after renovation. The ventilation will only have to compensate 15% of the total heat dissipated from the converters, while it is 100% today.

3.2.3 Water cooling

The last major energy consumer of the East Area is the water-cooling systems designed to cool the magnets and, after the renovation, the power converters, given that they dissipate up to 85% of the energy they consume.

As mentioned previously, the cycled mode will significantly reduce the heat dissipation of the magnetic components and the power converters. Based on the power losses calculated for the electricity consumption of the magnets and the power converters, the cooling needs can be easily retrieved. The annual cooling needs will massively drop from 4162 MWh to a mesmerizing 369 MWh (91% decrease).

Heat from East Area magnets and power converters is mainly absorbed by the demineralized water circuit, passed to cooling tower water, and ultimately released to the atmosphere. The cooling tower is a heat exchanger (air/water) of open wet type, meaning it partially evaporates and thus consumes the circuit's raw water to bring its temperature down.

As for the electricity consumption, which is predominantly caused by the water pumps generating the required water flow inside the circuit, a corresponding decrease will be observed. Due to a careful pump selection, the number of pumps in operation can be reduced from two to one. Combined with the fact that the new pump differential pressure will be reduced from 24 to 12 bar and the water flow will be 275 m³/h instead of 300 m³/h, the corresponding electricity consumption will also drop from 4246 to 1597 MWh, consequently saving 76% in energy consumption.

3.2.4 Conclusion and outlook

As a result, the total energy consumption will decrease by 81% after renovation and for the thermal energy consumption (heating and cooling needs combined), a saving of 82% will be attained, as illustrated in Fig. 3-24, which compares the energy flows by type (cooling, heating, electricity) before and after consolidation.

Additional operational improvements can be implemented. Firstly, by switching off equipment such as power converters while not in use (e.g. during technical stops). Secondly, replacing the water pumps of the water-cooling circuit can provide additional savings as they will be oversized after the renovation [3]. Finally, a renovation of the power converter building, which was constructed around the same period as the main experimental hall and shows, today, the same insulation issues, should be considered.

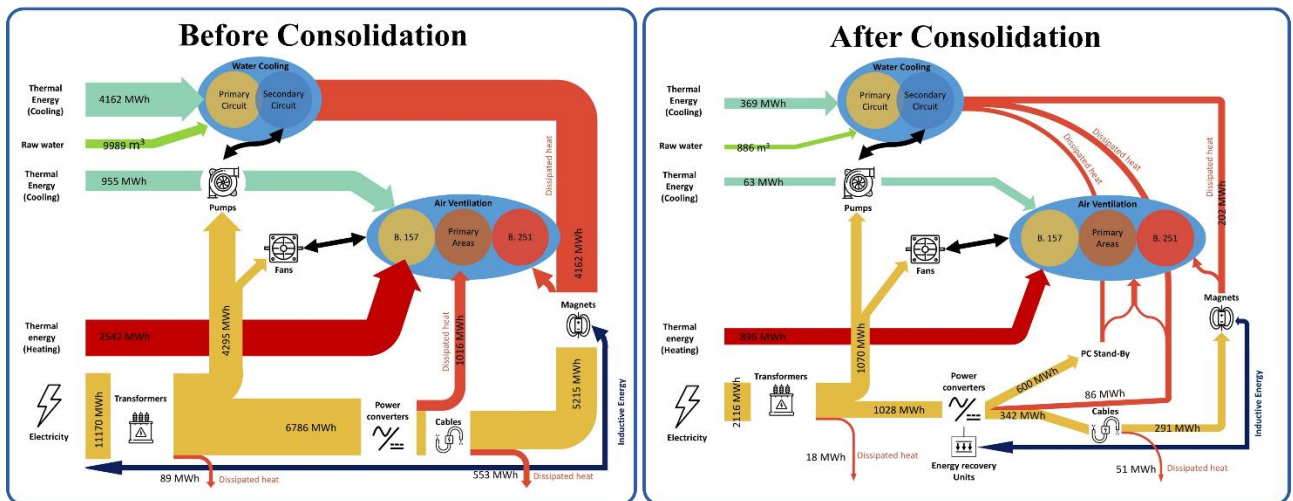


Fig. 3-24: Summary diagrams of estimated energy consumption before and after renovation.

3.3 Impact on radioprotection and general safety

3.3.1 Introduction

The design, construction, commissioning, operation, and eventual dismantling of the East Area comply with the standard CERN safety rules and applicable regulation. Following an initial risk assessment 0, the project

was classified as a project with major safety implications and will thus need a safety clearance from the CERN safety authority before the facility is operated.

This section describes the main safety checks to be performed throughout the lifecycle of the project. This work is continuously documented in the safety file of the facility and will be issued before the first beam extraction to the East Area.

3.3.2 Impact on radioprotection

3.3.2.1 Air activation

The design goals for the ventilation system of the East Area renovation project are the following.

- i) The committed effective dose due to inhalation has to be less than 1 μSv for a 1 hour long access.
- ii) The effective dose to the reference group for members of the public should be less than 1 μSv per year, from combined prompt radiation (sky shine) and from releases to the environment.

The methodology to obtain the radionuclide concentrations, the annual release to the environment, and the resulting annual effective dose to members of the public is based on the weighting of track-length spectra in air, obtained by FLUKA Monte Carlo simulations [8][9] with a dedicated set of air activation cross-sections [10][11], taking the time evolution, the characteristics of the ventilation circuit, and the beam parameters [11] into account and finally applying conversion coefficients from released activity to effective dose, computed with the dedicated Monte Carlo integration program EDARA [12]. A detailed description of this methodology, including the location of the reference group, can be found in Ref. [13].

3.3.2.1.1 Primary zone

The ventilation system for the primary zone will provide dynamic confinement with a forced air extraction rate between one and ten air renewals per hour. A flush of the primary zone resulting in 3 volume exchanges is mandatory before granting access to the primary zone.

All releases from the ventilation system of the primary zone to the environment will be monitored by a dedicated ventilation monitoring station [14]. The release point will be a dedicated chimney above the roof of the East Hall.

Based on these conditions, an air activation study has been performed [15]. The effective dose to the reference group for members of the public from releases of airborne radioactivity to the environment will be less than 0.2 μSv per year. The committed effective dose due to inhalation will be well below 1 μSv for a 1-hour long access. Therefore, both design goals with respect to the air activation for the primary zone will be achieved.

3.3.2.1.2 Mixed zone

A dedicated air activation study has been performed for the mixed zone [16], investigating both dynamic confinement and static confinement configurations.

The release from the mixed zone is negligible with respect to the target zone, even for dynamic confinement.

The committed effective dose due to inhalation was calculated by integrating over the 1-hour exposure time after a cool-down period of 30 minutes without flush before access as a function of the air exchange rate. Even for static confinement, the committed effective dose due to inhalation is far below 1 μSv for a 1-hour long access. In addition, it is also negligible with respect to external exposure due to residual radioactivity.

Therefore, the connection of the mixed zone to the primary ventilation system (V1, V2, and V3) is not required for radiation protection purposes, although a minimal airflow has to be ensured (see Fig. 3-25).

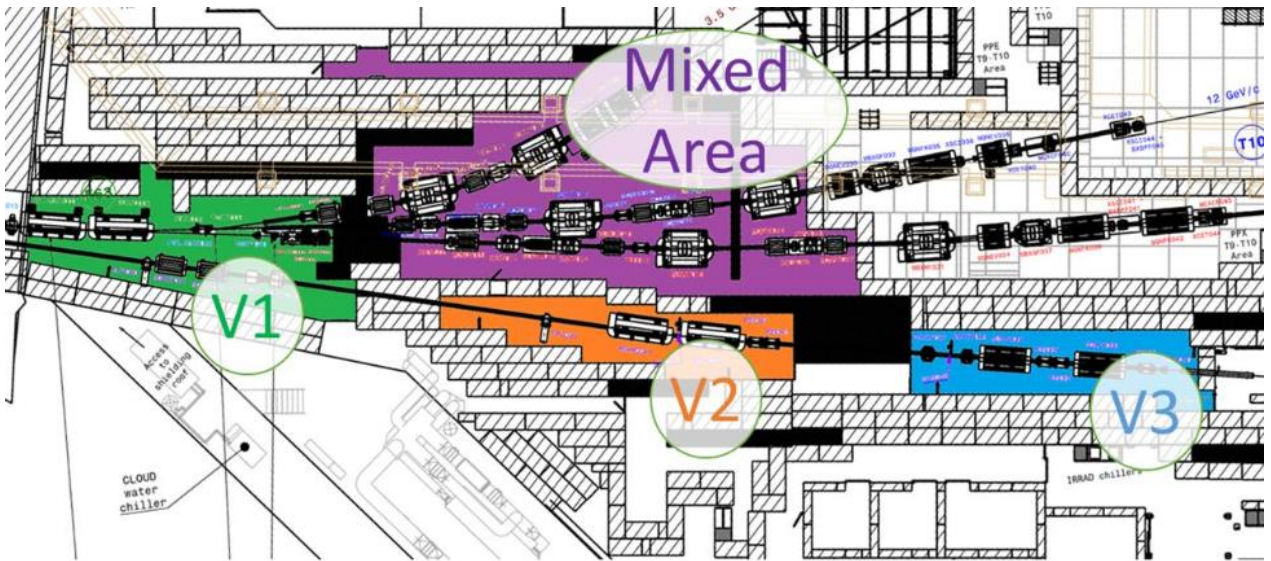


Fig. 3-25: Location of the primary zone bunkers (V1, V2, and V3) and the mixed area.

3.3.2.2 Water activation

Activation of the water used for the cooling of equipment, such as magnets, will radiologically only be significant in the primary zone. Following best practices in water circuit design in radiation areas, the water circuits for the primary zone shall be separated from the water circuits of the other parts of the East Hall, including the mixed zone. The water circuits for the primary zone can be connected with the one for IRRAD and CHARM since these two facilities also receive primary beam (see Section 5.2). All water circuits will be equipped with sampling points that allow the extraction of water samples for radiological analysis.

3.3.2.3 Radiation protection aspects of the access system

The primary zone will be classified at least as a Limited Stay Radiation Area due to the residual radiation levels [17]. Therefore, a Radiation Protection veto has to be implemented at the access point that grants access to the primary zone, as is the case today [18]. The access system also has to verify that the flush of the primary zone (see Section 5.8) has been completed before granting access to the primary zone. The access to the mixed zone is excluded from this requirement.

3.3.3 Impact on conventional safety

3.3.3.1 Electrical design report for the capacitors

The new SIRIUS power converters in Building 251 include energy storage units that consist of capacitors that recover the energy sent to the magnet at every pulse. These capacitors can in total store an energy of 10 MJ. The design of the power converter included an in-depth investigation of the failure mechanisms to assess the damage that could be caused by a failure of these systems and take measures to reduce the probability of occurrence of such events. In addition, collective measures should be taken to suppress any risk to the teams working near the converters (see Section 4.2).

3.3.3.2 Structural validations

The general renovation of Building 157 requires a careful study of the structural resistance of the facility. Starting from the slab load capacity to make sure that, during all the phases of the worksite until the final configuration, no overloading happens. The assembly of shielding blocks itself needs to be validated both in its static resistance and in its stability in case of earthquake.

3.3.3.3 Access systems

The primary area size has been reduced to limit the need to access the most radioactive area so a new zone, called the mixed zone, has been created. Similarly, a new zone called T09-10 has been created to suppress the unnecessary access to beamline to the users working in the experimental areas (Fig. 3-26).

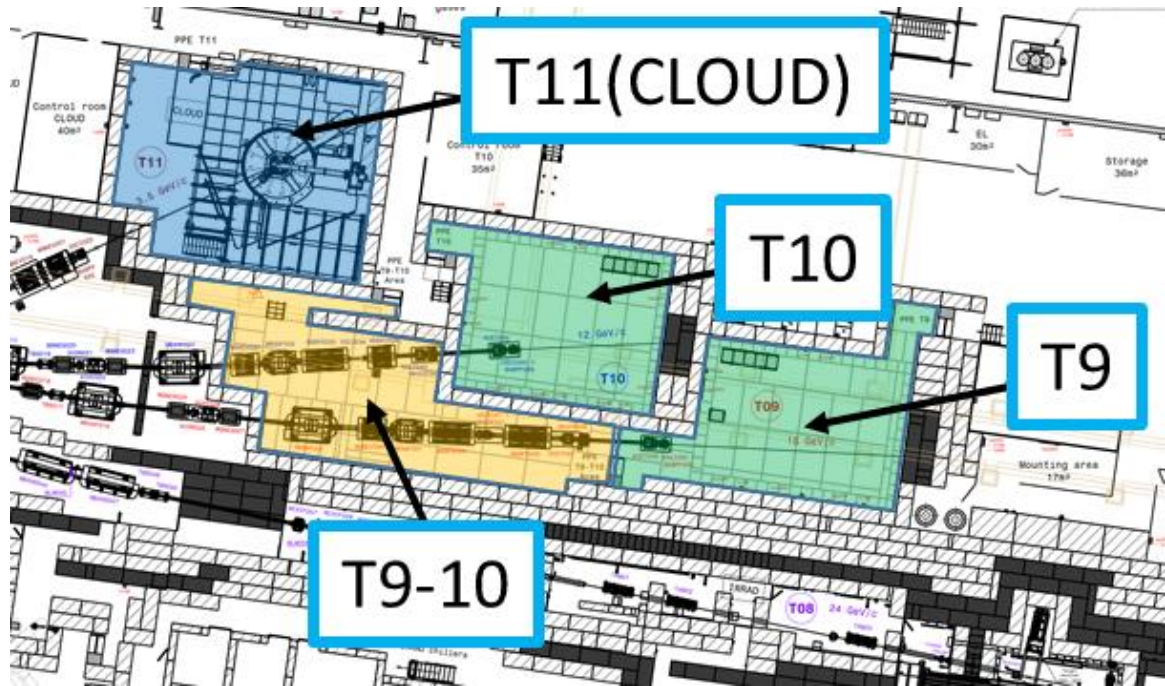


Fig. 3-26: View of the experimental areas (T09, T10, and T11) and the T09-10 area.

These changes will be integrated into the new access system to only allow access to the various areas in safe conditions: link between access mode and the new ventilation, beam stoppers protecting downstream areas, RP Veto, etc. (see Section 5.8).

3.3.3.4 Gas systems

The new gas system will follow the applicable standard, especially regarding flammable gases. Atmosphere EXplosible (ATEX) areas will be defined and proper systems implemented, such as ATEX ventilation (see Section 5.10) and gas detection systems (see Section 5.9).

3.3.3.5 General safety checks

Throughout the lifecycle of the project, mandatory checks will be performed. For instance, design validation by the relevant experts or safety acceptance when equipment is manufactured or/and installed.

References

- [1] L. Gatignon, The East Area upgrade - specifications and cost estimates, [EDMS 1471844](#) (2016).
- [2] K.L. Brown, and C. Iselin, Decay TURTLE: a computer program for simulating charged particle beam transport systems, including decay calculations, CERN-74-2 (1974), <http://dx.doi.org/10.5170/CERN-1974-002>.

- [3] R Vanhoutte, *et al.*, Design & Optimization of the Alignment Supports for the New Laminated Magnets for the CERN East Area Consolidation Project, IPAC 2019, THPRB086, <http://dx.doi.org/10.18429/JACoW-IPAC2019-THPRB086>.
- [4] B. Carlsen. Preliminary thermal study of Building 157, 20 December 2017, [EDMS 1886407](#) (2017).
- [5] F. Dragoni, East Area Hall Renovation: Primary Zone Ventilation System Users' Requirements, [EDMS 1871830](#) (2018).
- [6] A. Henriques, Launch safety agreement – East Area Renovation, [EDMS 1731887](#) (2017).
- [7] T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov, and V. Vlachoudis, *Nuclear Data Sheets* **120** (2014) 211, <https://doi.org/10.1016/j.nds.2014.07.049>.
- [8] A. Ferrari *et al.*, FLUKA: a multi-particle transport code, CERN (2005), CERN-2005-10, INFN/TC_05/11, SLAC-R-773, <http://dx.doi.org/10.5170/CERN-2005-010>.
- [9] M. Huhtinen, Determination of cross-sections for assessments of air activation at LHC, CERN (1997), CERN/TIS-RP/TM/96-29, <https://cmsdoc.cern.ch/~huu/airxsecs.ps>.
- [10] M. Brugger *et al.*, Effective dose to the public from air releases at LHC point 7, CERN (2004), CERN-SC-2004-064-RP-TN, [EDMS 493681](#).
- [11] M. Lazzaroni, J. Bernhard, and E. Harrouch. Beam stopper, stopper dump and target, [EDMS 1786687](#) (2018).
- [12] P. Vojtyla, Models for environmental impact assessments of releases of radioactive substances from CERN facilities, CERN-SC-2005-005-IE (2005), [EDMS 607969](#).
- [13] R. Froeschl, Radiation protection assessment of the proton irradiation and the CHARM facility in the East Area, CERN-RP-2014-008-REPORTS-TN (2014), [EDMS 1355933](#).
- [14] D. Perrin, Description of the CERN radiation and environmental monitoring system, CERN-RP-2017-027-REPORTS-TN (2017), [EDMS 1723230](#).
- [15] R. Froeschl, Preliminary air activation and release assessment for the East Area upgrade, [EDMS 1837040](#).
- [16] E. Iliopoulou, and R. Froeschl, Status update on the RP assessment for the East Area Renovation Project, [EDMS 1974733](#).
- [17] D. Forkel-Wirth, Zonage radiologique au CERN, [EDMS 810149](#) (2007).
- [18] G. Dumont, Radiation veto configuration PS complex, CERN-DG-2009-097-RP-TN (2009), [EDMS 1043334 v2.1](#).

Chapter 4 Beamline – main components

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4.1 Magnets

4.1.1 Introduction

The East Area renovation will cover the refurbishment of the East Hall with its beamlines and infrastructures. As defined in Section 2.1, a re-design of the beamlines is included to improve the magnet situation, the radiation situation, and maintainability in general. Thanks to a cycled powering mode of the magnets instead of a steady state one, considerable energy savings will be possible. Therefore, several magnet families have to be re-designed to be in accordance with the purposes of the project.

The new East Area magnet system consists of 12 different designs with a total of 58 magnets among which 15 are bending magnets, 31 are quadrupoles, and 12 are correctors. In the Proton Synchrotron (PS) area (Building 352), the primary area (Building 157), and the line T08 (Building 157), the magnets will be cycled every 2.4 s. This concerns the lines F61, F62, part of F63, and T08. The other lines, T09, T10, and T11, will be cycled with a period of 4.8 s. Cycling the magnets is an important constraint for the construction of the magnetic parts (yokes). In addition, the coils have to be adapted to match the power supply specifications. The magnets have to be laminated to avoid eddy currents and large delays between the magnetic field and the current application. All laminated magnets currently used and needed in the new in the East Area layout will be refurbished, this concerns four families (or 22 units). The new magnets will be manufactured by industry according to CERN’s design.

Another constraint is the magnet overall size limitations. As the layout was fixed at the beginning of the project, all new large magnet designs had to have the same length and width as the present ones. This complicates the designs, as laminated yokes need a larger mechanical structure around the yoke to maintain the laminations. The total lengths and widths have been discussed with the integration team and after few iterations a solution was found and the final designs approved.

4.1.2 Bending magnets

Seven C-shaped bending magnets and eight H-shaped bending magnets will be installed in the East Area beamlines. The C-shaped ones are the refurbished MCB bending magnets [1] and the H-shaped will be two new families with different overall lengths from the existing ones but with the same cross-section, the M100 L [2] and M200 L [3]. In Fig. 4-1 it is possible to see the location of these magnets in the East Area.

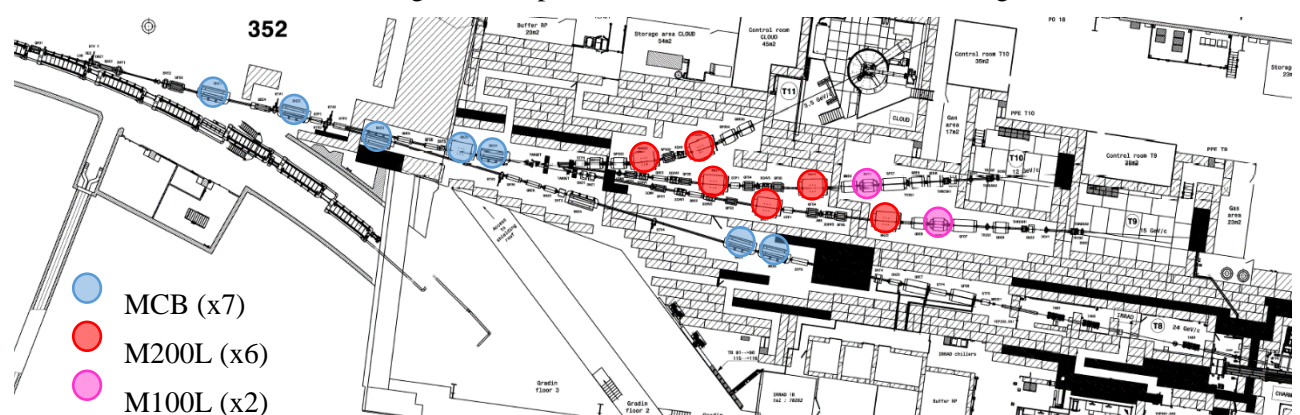


Fig. 4-1: Bending magnet EEA layout.

4.1.2.1 MCB bending magnets

This type of magnet is being repurposed from old magnets back from the 1970s (see Fig. 4-2). They are part of the bending magnet families made for the Intersecting Storage Ring (ISR) beam transfer system [4]. They are widely used at CERN, in the Experimental Areas, Super Proton Synchrotron (SPS) North Area (NA), and in T10 transfer line. Fourteen units are being used and seven spares are available. The range of integrated field required for the Experimental Areas is from 2.05 to 4.4 Tm, the maximum achievable.

Three of the existing MCB need to be modified before their installation due to the limited power converter voltage; the maximum cycled integrated field achievable with one converter in a 2.4 s period is 3.2 Tm. The large inductance requires the upper and lower coils to be powered separately by two converters. With these different specifications, in addition of the seven units, one spare of each type (four magnets with a single converter and three magnets with two converters) will be prepared, see Table 4-1.

Table 4-1: MCB bending magnet characteristics.

Number of magnets	4 + 1	3 + 1
CERN code	PXMBXHDCWP	
Electrical circuits	1	2
Short name	MCB / HB2	
Aperture [mm]	80	
Iron length [mm]	2 500	
Total length [mm]	3 120	
Total width [mm]	1 246	
Total height [mm]	1 250	
Weight [kg]	20 500	
Nominal current [A]	880	
Resistance [mΩ]	165	2 × 82.5
Inductance [mH]	640	2 × 320
Power at nominal current [kW]	128	2 × 64
Delta P nominal [bar]	15	
Nominal cooling flow [l/min]	56	
Total number of turns	204	2 × 102
Nominal field [T]	1.74	
Integrated field [Tm]	4.44	

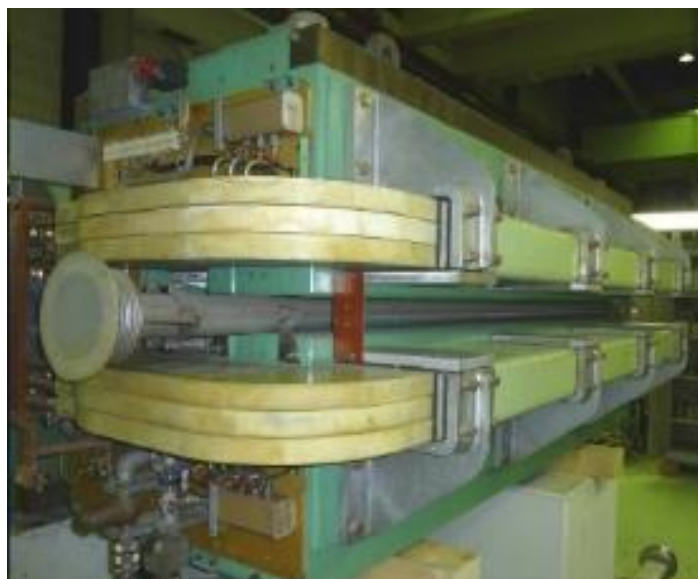


Fig. 4-2: MCB magnet.

4.1.2.1 New M100 L and M200 L bending magnets

These two new families are laminated versions of the present M100 [5] and M200 [6] built in the 1960s, and are mainly used in the experimental areas and where large apertures are needed. The present massive yoke design can vary its aperture gap between 110 and 200 mm by adding steel plates between the two half-yokes. This option of gap modification cannot be applied easily to laminated yokes. A schematic representation of these magnets can be found in Fig. 4-3. The most important constraints for these two designs were the overall sizes to fit in the layout, and the number of turns to match the characteristics of the power supplies. In the first stage of the project, it was foreseen that the existing coils could be kept but, due to their too high inductance, the number of turns had been reduced. The range of integrated fields required for the M100 L is 1.5 Tm and from 2.5 to 3 Tm for the M200 L (see Table 4-2).

Table 4-2: M100 L – M200 L bending magnet characteristics.

CERN code	PXMBXHFHWP	PXMBXGFHWP
Short name	M100 L	M200 L
Number of magnets	2 + a set of coils	6 + a set of coils
Aperture [mm]	110	140
Iron length [mm]	1 000	2 000
Total length [mm]	1 730	2 730
Total width [mm]	1 820	1 820
Total height [mm]	1 300	1 300
Weight [kg]	17 100	33 000
Nominal current [A]	985	1 300
Resistance [mΩ]	58.1	83
Inductance [mH]	280	428
Power at nominal current [kW]	56.4	139
Delta P nominal [bar]	3	7.1
Nominal cooling flow [l/min]	50.4	67.2
Number of turns per pole	96	96
Nominal field [T]	1.646	1.716
Integrated field [Tm]	1.821	3.585

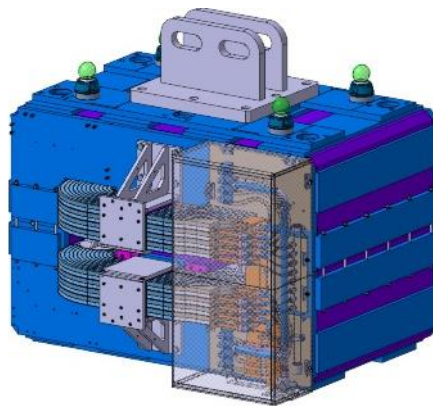


Fig. 4-3: New M100 L 3D CAD view.

4.1.3 Quadrupole magnets

Seven types of quadrupoles are needed for the EA renovation, as illustrated in Fig. 4-4. Available laminated designs, the QDS [7], QFS [8], and QFL [9], are families built in the 1970s for the ISR beam transfer lines, as with the MCB. Like the M100 and M200, the present Q100 [10] and Q200 [11] will be replaced by laminated versions: Q100 L [12] and Q200 L [13]. New Q74 L [14] and Q120 C [15] will substitute the actual magnets, only used in the EA, due to their poor state and high radiation activation.

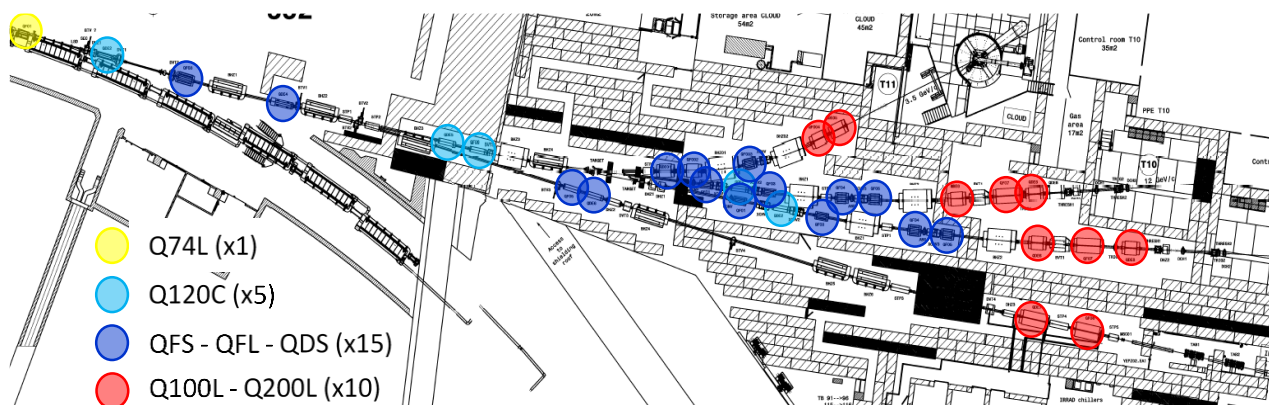


Fig. 4-4: Quadrupole magnet EA layout.

4.1.3.1 QDS – QFS – QFL quadrupole magnets

The required quantity of magnets is covered by the spare ones stored. They will be tested, disassembled, cleaned, improved, reassembled, certified, and magnetically measured. They are also commonly used at CERN; 57 units are currently in operation mainly in the transfer lines and experiment areas. The maximum required integrated gradients are 10.7, 12.2, and 19.5 T for the QDS, QFS, and QFL, respectively (see Table 4-3). In Fig. 4-5 there are photos of these magnets assembled.

Table 4-3: QDS – QFS – QFL quadrupole magnet characteristics.

CERN code	PXMQNDCTWP	PXMQNEGTWP	PXMQNEFTWP
Short name	QDS	QFS	QFL
Number of magnets	4 + 1	8 + 1	3 + 1
Aperture [mm]	91	100	
Iron length [mm]	820	800	1 200
Total length [mm]	1 080	1 080	1 481
Total width [mm]	600	844	
Total height [mm]	900	1 000	
Weight [kg]	1 600	2 900	4 200
Nominal current [A]	500		
Resistance [mΩ]	59	62	96
Inductance [mH]	45	80	120
Power at nominal current [kW]	15	16	24
Delta P nominal [bar]	5		
Nominal cooling flow [l/min]	8	8	12
Number of turns per pole	34	41	
Nominal gradient [T/m]	19.2	18.9	
Integrated gradient [T]	16.3	15.7	23.2



Fig. 4-5: QDS – QFS – QFL magnets.

4.1.3.2 New Q100 L – Q200 L quadrupole magnets

These two new families are laminated versions of the Q100 and Q200 built in the 1960s and mainly used in the experimental areas and where large apertures are needed. The current designs have massive yokes and coils that are in poor shape. The reuse of the current coils is not foreseen for reasons of reliability. Both families have the same cross-section and only the iron length differs: at one (Q100 L) and two metres (Q200 L). The maximum required integrated gradients are 11.8 and 20 T for the Q100 L and Q200 L, respectively (see Table 4-4).

As with the Q100 L and Q200 L designs (Fig. 4-6), the more important constraint for the design was the overall length to fit in the layout. The width can be increased, as long as the actual supports can be used, but not the length. The iron lengths will be identical as in the present designs, consequently the coil and mechanical designs have to be adapted.

Table 4-4: Q100 L – Q200 L quadrupole magnet characteristics.

CERN code	PXMONEVTWP	PXMONEFKTWP
Short name	Q100 L	Q200 L
Number of magnets	5 + a set of coils	
Aperture [mm]	200	
Iron length [mm]	1 000	2 000
Total length [mm]	1 460	2 480
Total width [mm]	1 200	
Total height [mm]	1 200	
Weight [kg]	7 000	11 500
Nominal current [A]	800	
Resistance [mΩ]	158	249
Inductance [mH]	166	320
Power at nominal current [kW]	101	159
Delta P nominal [bar]	4	7
Nominal cooling flow [l/min]	86	91
Number of turns per pole	70	70
Nominal gradient [T/m]	11.5	
Integrated gradient [T]	12	24

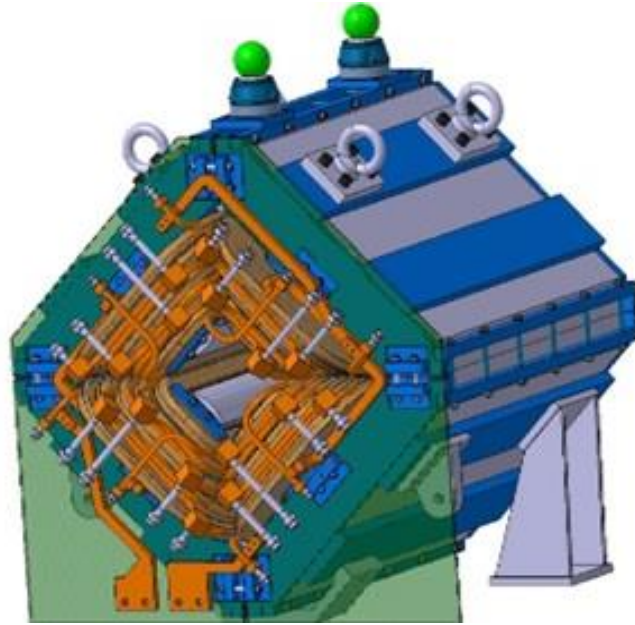


Fig. 4-6: New Q100 L 3D CAD view.

4.1.3.3 New Q74 L and Q120 C quadrupole magnets

The Q74 [16] is the first magnet of the F61 extraction line and the place available is limited by the space between the magnet vacuum chamber and the PS ring vacuum chamber, see Fig. 4-7. Only a Collins quadrupole shape can be designed to avoid using space intended for the magnetic return yokes. The required integrated gradient is 31 T (see Table 4-5).

The present Q120 [17] magnets, although laminated, have to be substituted by new magnets due to the high level of radiation accumulated over a 12-year period in the primary area. As for the Q74, these magnets are placed close to the line separations, between F62 and T08, and therefore will be Collins shaped. The required integrated gradient is 19 T (see Table 4-5). For these two designs, we take advantage of the need for replacement to improve the pole shapes, coil configurations, and cooling system to have a higher reliability.

Table 4-5: Q74 L and Q120 C quadrupole magnet characteristics

CERN code	PXMQNCL8WP	PXMQNEL8WP
Short name	Q74 L	Q120 C
Number of magnets	1 + 1	5 + 1
Aperture [mm]	50	100
Iron length [mm]	700	1 200
Total length [mm]	1 000	1 360
Total width [mm]	225	415
Total height [mm]	420	600
Weight [kg]	600	1 939
Nominal current [A]	800	600
Resistance [mΩ]	75	600
Inductance [mH]	1.7	48
Power at nominal current [kW]	821	48.2
Delta P nominal [bar]	6	6.4
Nominal cooling flow [l/min]	26	31
Number of turns per pole	16	33
Nominal gradient [T/m]	47	18.4
Integrated gradient [T]	33	22.9

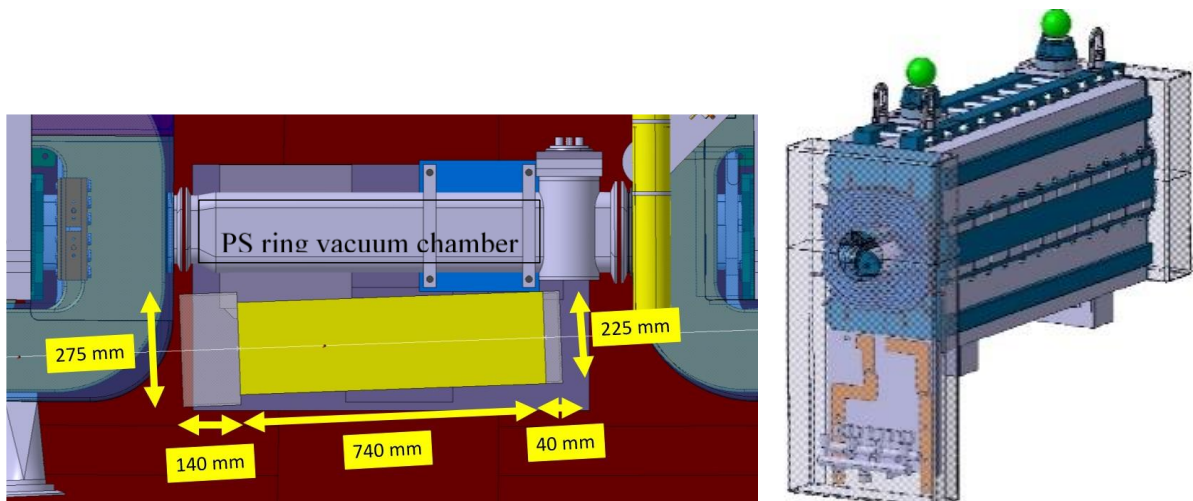


Fig. 4-7: Left: top view of Q74 maximum overall dimensions; right: new Q120 C 3D CAD view.

4.1.4 Corrector magnets

Two types of correctors are needed for the EA renovation (see Fig. 4-8). Some requirements could have been fulfilled with the existing massive magnets such as the MEA19 [18] or MDX [19] but, due to the eddy currents, the delay between field and current is at the limit of the cycle time required. The lengths available for these two designs are limited by the new layout of the beamlines and challenging compromises have been made between the magnet design and beam optic.

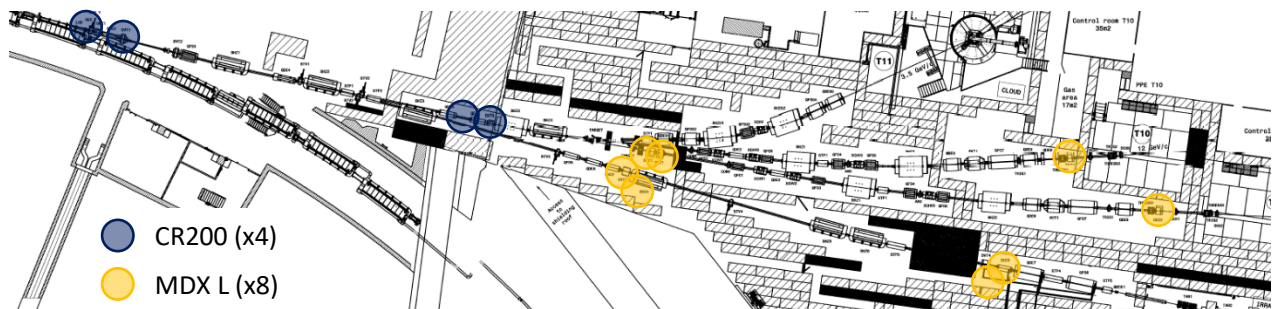


Fig. 4-8: Corrector magnets EA layout.

4.1.4.1 New CR200 and MDX L corrector magnets

The CR200 [20] corrector (Fig. 4-9) is a large aperture magnet tightly fitted between two quadrupoles. Its design has been optimized to minimize the magnetic coupling between these magnets with a three-dimensional study [21]. With the first requirement of a large aperture, at 150 mm, the CR200 corrector was not feasible. Therefore, the aperture was reduced from 150 to 100 mm. Even with this aperture reduction, the distance available between the adjacent magnets is at the limit of a realistic magnet's overall length. The magnetic coupling between these magnets has been studied, and proven to be negligible in terms of integrated magnetic homogeneity (see Table 4-6).

The new MDX L 150 [22] is a laminated version of the actual MDX. As the M100 and M200 are massive, the aperture of the actual MDX can vary its gap between 52 and 120 mm by adding steel plates between the two half-yokes. This option of gap modification cannot be applied easily to laminated yokes. A few different gaps were foreseen but, in order to have as few as possible different designs, it was decided to do only one type with an aperture of 150 mm (see Table 4-6).

Table 4-6: CR200 and MDX L corrector magnet characteristics.

CERN code	PXMCXCEHWP	PXMCXCFHWP
Short name	CR200	MDX L 150
Number of magnets	4 + 1	8 + 1
Aperture [mm]	100	150
Iron length [mm]	200	400
Total length [mm]	500	655
Total width [mm]	830	730
Total height [mm]	700	680
Weight [kg]	910	1 100
Nominal current [A]	600	240
Resistance [m Ω]	40.8	240
Inductance [mH]	22	300
Power at nominal current [kW]	14.7	221
Delta P nominal [bar]	10	10
Nominal cooling flow [l/min]	7.1	9
Number of turns per pole	64	180
Nominal field [T]	0.9	0.7
Integrated field [Tm]	0.28	0.36

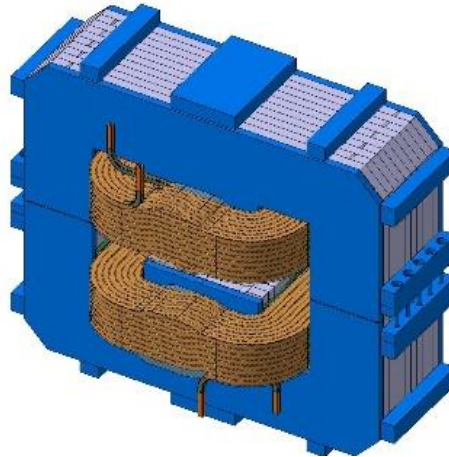


Fig. 4-9: New CR200 3D CAD view.

4.2 Power converters

4.2.1 East Area present situation

The EA powering is presently supplied by 65 power converters that are located in Buildings 251 and 263. There are 47 power converters in Building 251 and 18 power converters in Building 263.

A study has been performed in 2012 [22][23][24] by the electrical power converters group showing that the energy consumption of East Area could be reduced from 11 GWh to 0.6 GWh per year after Long Shutdown 2 (LS2). A significant part of this saving could be obtained by using a cycling magnet current, hence recovering and storing the magnet energy after each physics operation. The study also highlighted the possibility of self-funding part of the upgrade program, notably the power electronic converters, with a depreciation period of five years for this investment.

4.2.2 East Area future layout and operation

The future beamlines (as defined in Section 2.1) of EA consist of 58 magnets of 12 different types (see Fig. 4-10) to be powered by 61 power converters.

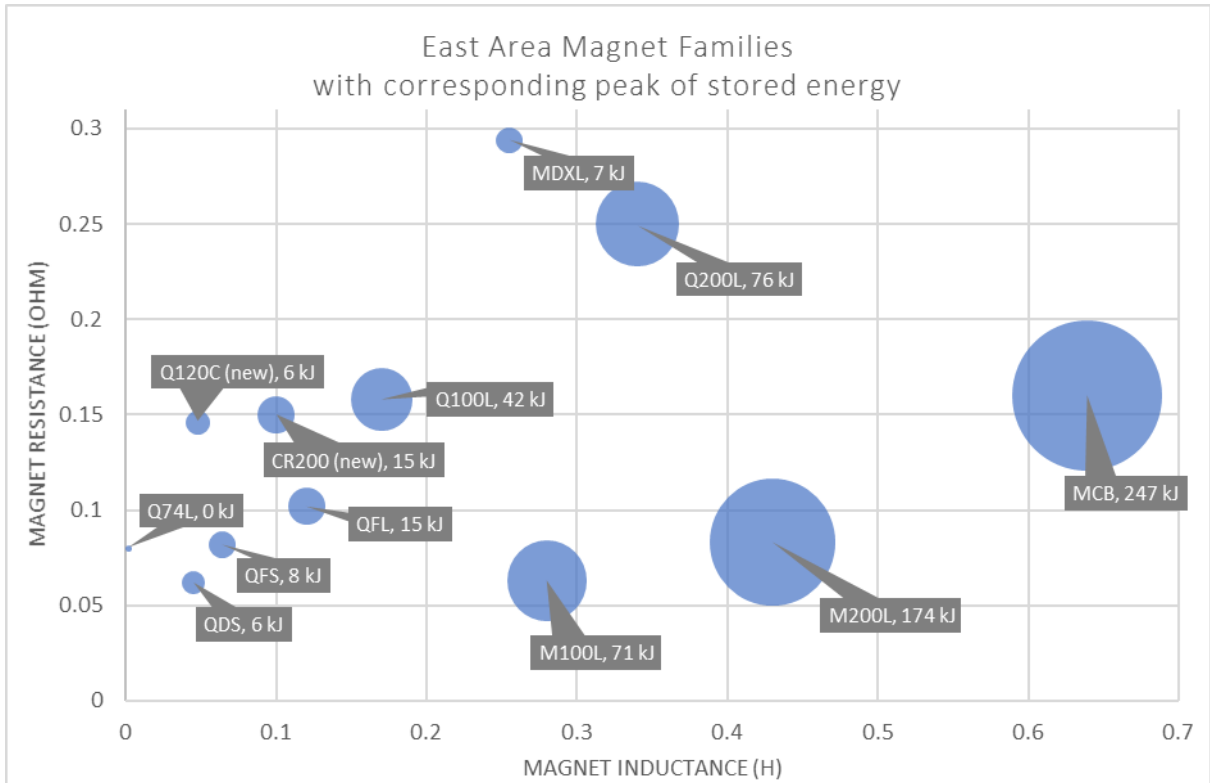


Fig. 4-10: The magnet map of East area. The axes correspond to the inductance and resistance of each magnet while the bubble size represents the peak stored energy (and hence the size of the magnet).

The beamlines and key bending elements are depicted in Fig. 4-11.

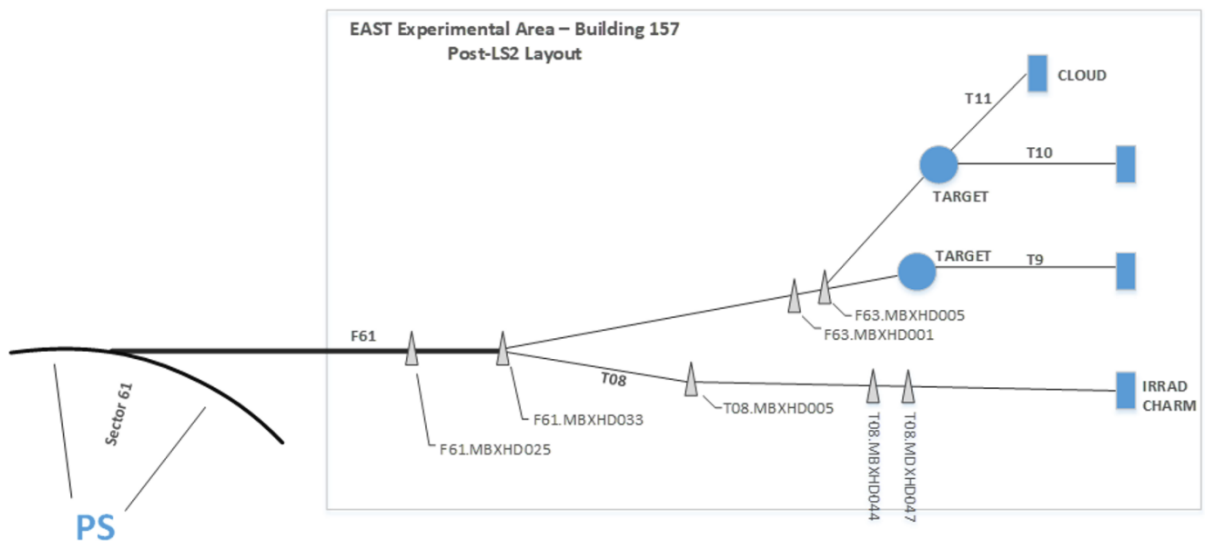


Fig. 4-11: The proposed East Area layout after LS2.

The new layout will operate with a cycling current in all magnets in order to save energy. The form of the cycle will be as illustrated in Fig. 4-12.

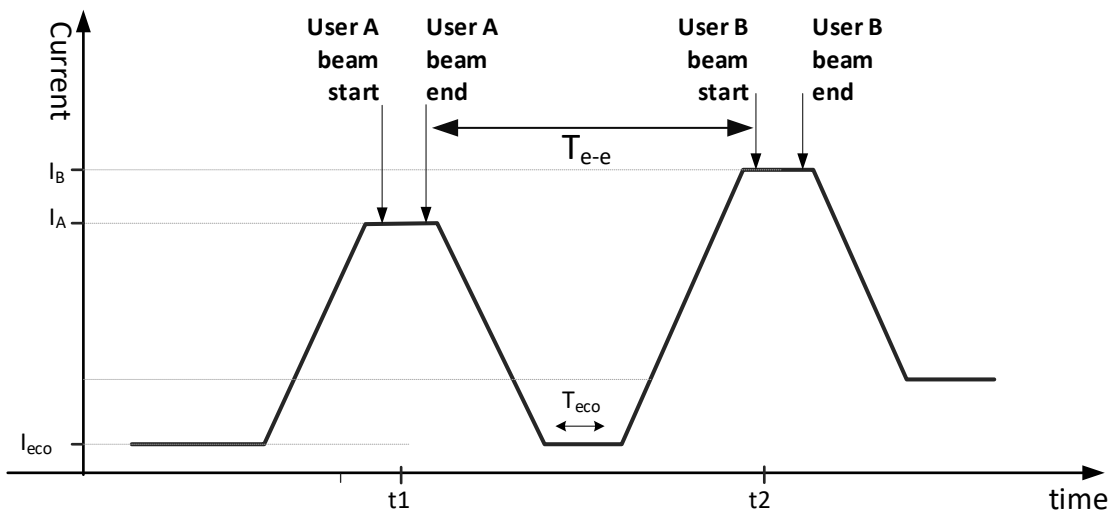


Fig. 4-12: Magnet current cycle in the new EA beamlines. The figure illustrates two successive beam extractions; one for user A and a second for user B. The typical duration of each beam extraction is up to 400 ms and the time between two successive extractions (T_{e-e}) is 1.93 seconds minimum. Certain lines will cycle with a 2.4 s period whereas others will have a 4.8 s period.

The duty cycle of the EA transfer lines will remain as it currently is at approximately 3.15 seconds (7 extractions of an approximate extraction duration of 470 ms each) in a typical super-cycle of 46.8 seconds. This implies a maximum duty cycle of 7% for the power converters (the time duration in a supercycle while extraction to the East Area takes place).

The cycle characteristics appear in Fig. 4-13. The extraction time lasts 400 ms with a spill start and end time tolerance of 10 ms on either side. Prior to the beam extraction, there is a maximum of 50 ms of current settling into the magnet. The precise requirements are discussed in Refs. [25][26].

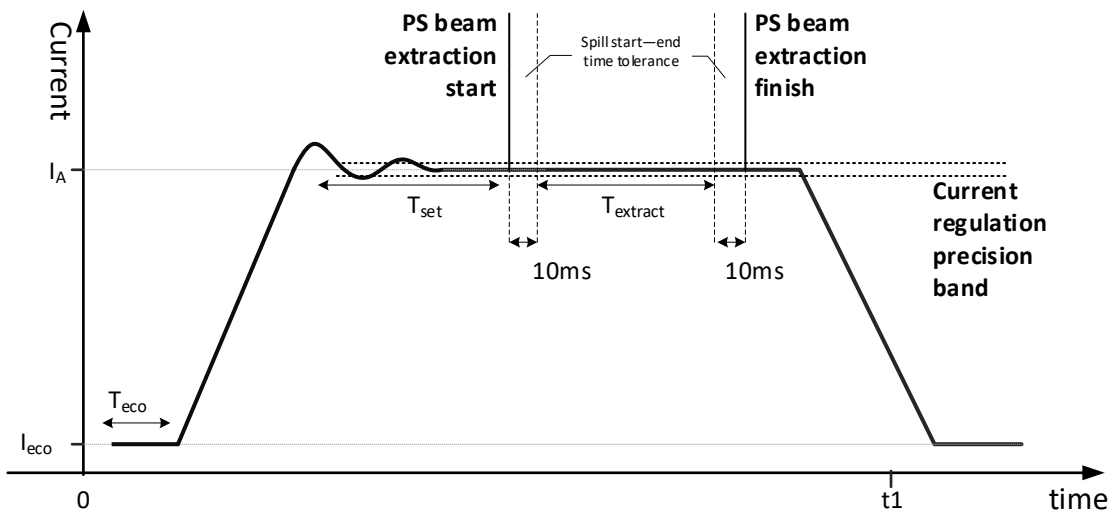


Fig. 4-13: Magnetic cycle characteristics. The settling time (T_{set}) allows for the current (and corresponding magnetic field) to settle to a value within the required precision. A tolerance of 10 ms is defined for the start and stop of the beam spill and hence for the beam extraction interval.

The root mean square (RMS) ratings of each circuit and losses in each circuit are listed in the following tables.

4.2.3 Powering solution

The present EA powering employs technology from the 1950s. Self-commutated thyristor converters were the state of the art at the time of construction and have been reliably supplying the East Area magnets for a very long time.

The proposed powering solution is based on the SIRIUS power converter family. The SIRIUS family (refer to Table 4-7) has been developed especially for Accelerator Transfer Line applications and performs magnet energy recovery after each magnetic cycle.

Table 4-7: Variants of the SIRIUS converter family.

Family	Type	Configuration	Grid supply (RMS values)	Output continuous	Output cycling peak
SIRIUS	S	Single module	400V/32A	200A/15kW	±450V/±450A
SIRIUS	2P	2 modules in parallel	400V/63A	400A/30kW	±450V/±900A
SIRIUS	4P	4 modules in parallel	400V/125A	800A/60kW	±450V/±1 800A
SIRIUS	4P+	4 modules in parallel with additional energy storing capacitors	400V/125A	800A/60kW	±450V/±1 800A

The power converter employs a diode rectifier (see grid supply in Fig. 4-14) followed by a boost regulator acting as a power network current flow controller. An intermediate energy storage stage supplies or absorbs the instantaneous peak power from the power converter load. Finally, the DC/DC magnet supply unit performs the high-precision current regulation in the electro-magnet load.

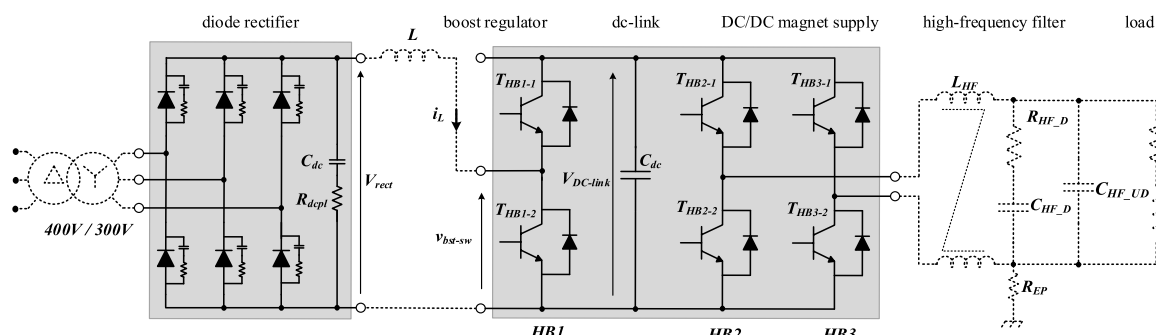


Fig. 4-14: Schematic of a SIRIUS S power converter module connected to a magnet.

SIRIUS 2P has been designed with fast cycling loads in mind and is able to recover magnet energy of up approximately 65 kJ. The power converter has been designed for a cycling rated voltage and current of 450 V and 900 A (with an RMS current of 400 A). However, it can supply a magnet with continuous (DC) output current with a current of up to 400 A, provided that the resistive magnet losses do not exceed the 30 kW input RMS power rating of the power converter. The unit can therefore provide a constant RMS power of 30 kW to the load whereas the peak cycling power deliverable to the magnet is 405 kW. The grid supply unit limits the power taken from the power network to 20 kVA with a 63 A/400 V three-phase line voltage. This unit serves to improve power quality towards the power network by limiting the input power fluctuation.

The SIRIUS power converter family (Fig. 4-15) has been designed mainly for cycling applications in transfer lines. Cycling applications tend to be more demanding on power electronic components as they trigger a number of effects, such as electromechanical stressing and thermal stressing (in particular in semiconductors and capacitors). A number of studies have been completed to that end to validate the design in terms of lifetime and safety, as listed in Table 4-8.

Table 4-8: References to studies performed during the development of SIRIUS.

Study	Relevant components	References
Accelerated aging testing	Electrolytic capacitors	[27][28]
Thermal cycling	Semiconductor switches (IGBTs)	[29]
Energy recovery	Control loops	[30][31][32]
Electrical Safety	Electrolytic capacitors, semiconductor power stack	[33]

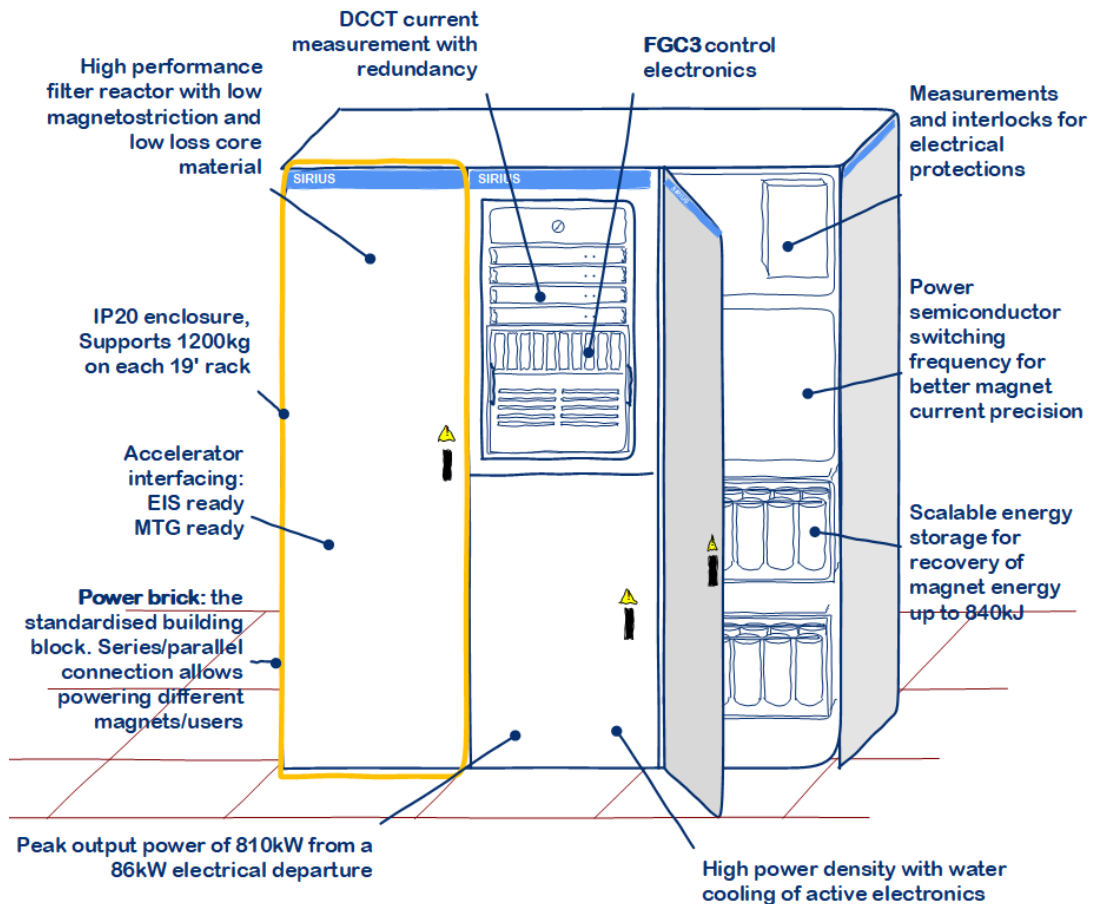


Fig. 4-15: Features of SIRIUS power converters family.

4.2.3.1 Spare converters and spare parts

Three power converters, one 2P and two 4P+, will be available in the East Area in case of malfunction of any of the operating power converters. All three can operate for a SIRIUS S in case of need. Interconnection of spare converters with the magnet load will be made by means of power cables that will be temporarily laid on the floor for the duration of spare converter operation.

4.2.3.2 MTG requirements

The machine timing generation (MTG) system is a programmable logic controller (PLC) based system that monitors the status of different components of the accelerators and reconfigures the supercycle of the machine accordingly. In the East Area, two power converters that direct the beam to the beam dump will be interfaced with the MTG system (see Table 4-9). Following a change of strategy of the Power Converters Group post-LS2, the EA power converters will not be interfaced to the MTG through a direct cable connection to the power converter. Instead, the MTG subscribes to a converter property that notifies the converter state.

Table 4-9: Power converters connected to the MTG system.

Power converter name	MTG interface
RPAEK.251.F61.RBXHD025A	Software (by subscription to FGC property)
RPAEK.251.F61.RBXHD025B	Software (by subscription to FGC property)

4.2.3.3 Elements important for safety (EIS) requirements

Two circuits will be part of an EIS-beam chain. In the case of a fault in one of the EIS power converters (see Table 4-10), a spare scheme has been proposed with a safe to operate switch-over system that obliges the operator to enable the EIS chain on the spare converter prior to connecting it to the EIS magnet [34].

Table 4-10: Power converters connected to the EIS system.

Power converter name	Type of EIS
RPAEK.251.T8.MBXHD044	Beam
RPAEK.251.T8.MBXHD047	Beam

4.2.3.4 Energy saving

A new energy saving mode has been conceived for the SIRIUS converters installed for the transfer lines. The algorithm runs in the FGC controller of the power converter. The operation requirements, such as the current value and extraction, of each physics user are processed together with the circuit parameters and a current waveform with the minimum possible RMS value is calculated prior to each magnetic cycle [35]. This process is transparent for the operation and relies on a timing event received from the gateway by the FGC controller over the FGCEther network. The timing will arrive 1.2 second prior to the extraction start instance so that enough time is available for reaching the user current, even for magnets with a large time constant.

4.2.3.5 Control facility

A control room will be constructed that will allow technical personnel to operate in a quiet environment for remote control and maintenance checks of the power converters.

4.3 Vacuum system description

The vacuum system of the EA will be renovated in the frame of the EA Renovation project: it includes the hardware (vacuum chambers, pumps, gauges, etc.) and the remote control system.

The current vacuum system installed in the East Area is a very old and unreliable system. The pumps are old, with a volume flow rate of 16 m³/h and with a very complex maintenance frequently required. Furthermore, the control system only shows the vacuum level (which is not available remotely) but it does not show the pumps' status.

For these reasons, it has been decided to change and to upgrade the entire vacuum system of the East Area, taking as a reference model the system installed in the North Area. The proposed vacuum system is in line with other vacuum systems at CERN, and has been optimized to minimize intervention time and exposure to radiation.

The system is equipped with on-line supervision to be monitored and controlled from the CERN Central Control room (CCC) and remotely from a PLC platform. With the new chosen components, it is possible to produce a 5×10^{-3} mbar vacuum.

The new vacuum system is divided into 5 sectors:

- i) Sector 1: from the BTV in F61 line until the 1st bending, in green in Fig. 4-16.
- ii) Sector 2: from the 1st bending to the 3rd bending in F62 and to the proton IRRADIation facility (IRRAD) in T08, in yellow in Fig. 4-16.
- iii) Sector 3: T09 line, in red in Fig. 4-16 .
- iv) Sector 4: T10 line, in pink in Fig. 4-16.
- v) Sector 5: T11 line, in grey in Fig. 4-16.

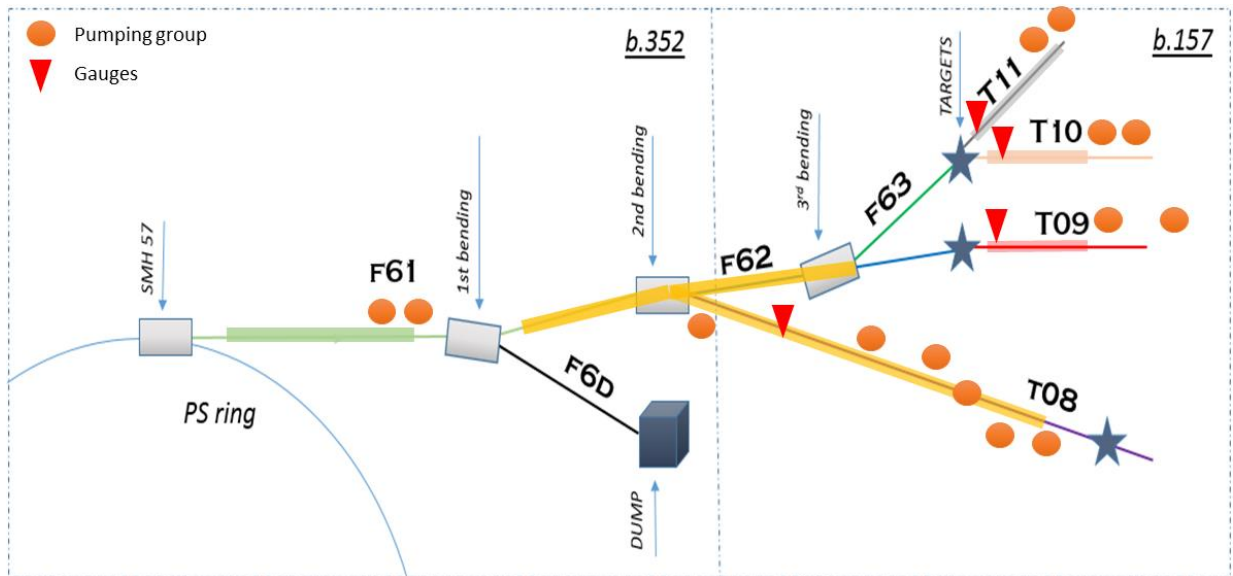


Fig. 4-16: Vacuum sectors of the East Area.

The new vacuum chambers are all in non-magnetic stainless steel (304L or 316L). Their standard size is DN219, but at some points, they have different dimensions to adjust to the beam’s radius and they depend on the outer equipment available space (magnets, collimators, etc.). The flanges used are conflate with metallic seals. The windows for each sector are made of mylar or aluminium and their thickness depends on the beam’s intensity and particle type.

Some cut-off manual section valves will be installed on the vacuum lines in order to isolate a part of the vacuum sector in case maintenance is needed on a piece of equipment.

4.3.1 Pumping groups

The new EA vacuum system has 14 pumping groups and four gauges located at different positions in the beamline. Each pumping group is made of valves, a gauge, a monitor, and a pump. The singular gauges are just to control the vacuum level in the system. The general layout and structure can be seen in Fig. 4-17 and more information is available in Ref. [36].

Inside the primary and mixed areas, no vacuum groups are installed because these areas are the most radioactive ones. In this way, it is possible to reduce the radiation damage to the pumps and the electrical systems, but also the exposure of the workers during maintenance. Inside the primary and mixed areas only four gauges are installed to monitor the vacuum level.

In some cases, the most critical vacuum groups (of more difficult access) will have two pumps mounted in parallel in order to have a redundant backup solution in case a fault occurs.



Fig. 4-17: Layout of the new vacuum system

4.3.2 Vacuum controls

The vacuum control system consists of a Siemens 1500 PLC, three sets of input/output (I/O) stations with a Profinet communication protocol and five total pressure gauge controller (TPG300), each with a set of Profibus, Pirani cards to receive the signal from the groups pumping. A supervisory control and data acquisition (SCADA) system based on the WinCC Open Architecture (OA) forms the remote interface with the users. The objective is to avoid radiation in the interventions on the pumping groups and on the Pirani gauges when the East Area receives the PS beam. The SCADA application will be implemented in the complex PS framework to include the East Area synoptic.

4.4 Beam intercepting devices

4.4.1 Introduction

The EA Beam Stopper Consolidation started before the Long Shutdown 1 (LS1). During LS1, a general maintenance was performed, including urgent interventions on the beam stoppers, such as the replacement of the compressed air distribution and the switches. During LS2, the layout of the beamlines will be modified. This will affect the layout and functionality of the beam stoppers, stopper dumps, and multitargets.

- Beam stoppers, stopper dump:

in particular the basic layout of the North branch will be revised completely. In the present beam layout, the primary protons that did not interact in the North multi-target are stopped in the T09 beam stoppers in case of access to T09. In the new layout those protons will be stopped in a fixed dump and the T09 stopper dumps will only see low-intensity secondary beams.

- Targets:

the new layout requires the installation of two multi-targets, one to produce the T09 beam and the second to produce T10 and T11 beam. The special target used in CERN High energy AccelRator Mixed field facility (CHARM) is not affected by the renovation.

4.4.2 Situation post LS2

4.4.2.1 Introduction

The validation work of the current beam stoppers [37] showed that their absorbing blocks are not suitable for present and future beam scenarios. Based on the experience gained over past years, a functional specification was drafted in order to set the requirements (see Table 4-11) for the design and operation of the new PS complex beam stoppers, including the East Area [41]. This stopper design will be used throughout the PS complex.

Table 4-11: Summary of requirement for new PS beam stoppers.

Life-time	Until 2048
Thermo-mechanical	< 15 repeated pulses
Material limit	$\sigma_e < \sigma_y(T)$ – von-Mises criterion (ductile materials)
Beam attenuation	Multiples of λ dependent on each PS line
Beam parameters	26 GeV/c, 2.3×10^{13} ppp (critical)
Beam passage	\varnothing 156 mm
Vacuum	5×10^{-3} mbar (EA) – 5×10^{-8} mbar (PS)
Integration	Flange-to-flange (< 884 mm)
Alignment	± 2 mm (core-beam centre), ± 0.5 mm flange centres (two chambers) Plug-in system, manual service connectors
Maintainability	Fully modularized Lock for OUT-BEAM core
Manufacturing	Rough core surface (passive cooling)
Fail-safe	Yes
Safety	at least two beam stoppers at each line (except secondary lines)

4.4.2.2 Stopper core design

The description, calculations, and design of the core are detailed in Ref. [42]. It has a diameter of 200 mm divided into four Inconel718 slices and one CuCr1Zr 400 mm thick slice. Figure 4-18 presents the different materials of the core design.

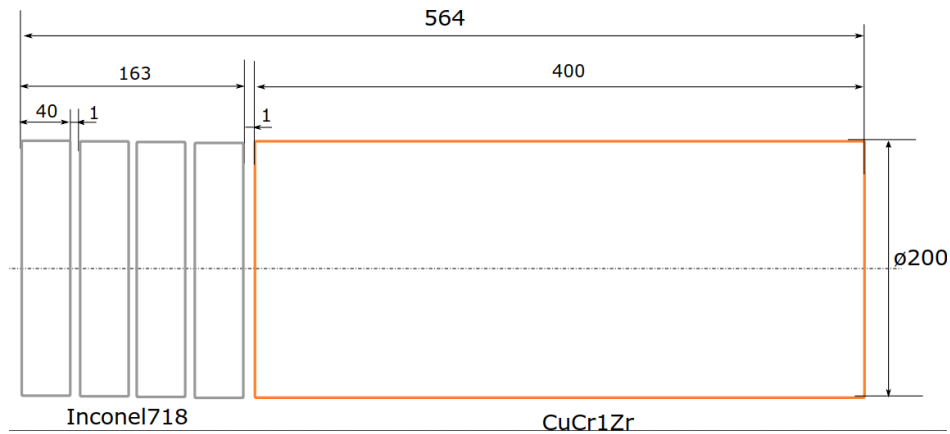


Fig. 4-18: Schematic representation of the core of the new PS beam stopper.

The core was designed to withstand 15 repeated pulses of the most critical beam in the PS complex (High Luminosity Large Hadron Collider (HL-LHC) beam, 26 GeV/c, 2.3×10^{13} protons per pulse). It is passively cooled through radiation to the vacuum chambers and heat conduction through supports.

The primary beam attenuation of the core is 3.8λ at 26 GeV/c, which corresponds to 97.8% of the incoming protons.

4.4.2.3 General description of the new beam stopper and stopper dump

Figure 4-19 shows the 3D model of the new beam stopper. This equipment is totally independent of neighbouring mechanical equipment, with its own vacuum chamber, mechanism, plug-in, and support systems. The new beam stopper has a weight of 550 kg and a height of 1 600 mm.

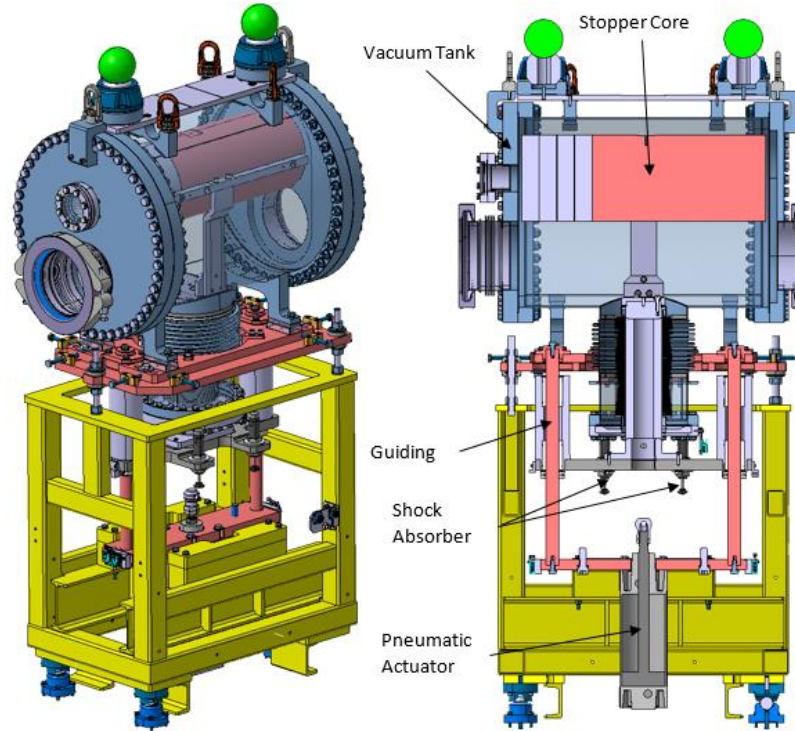


Fig. 4-19: Three-dimensional view and cut view of the new beam stopper.

The final design is composed of the following sub-systems, as shown in Fig. 4-20: the stopper core, which is held by a fork. The fork is welded to the bellows, which are themselves connected to the base plate. The shock absorbers and ball bearings are fixed onto this plate as well. The pneumatic actuator is also fixed below this plate.

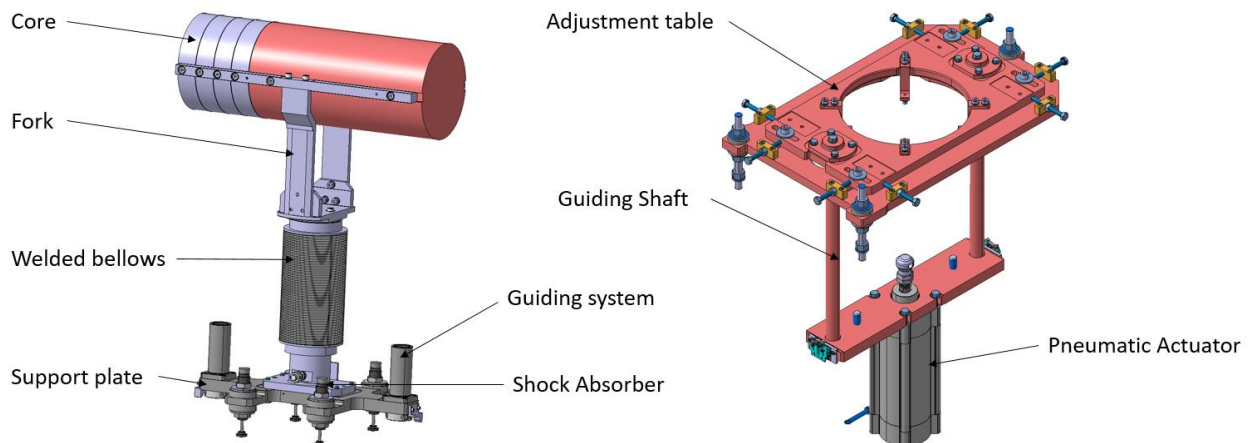


Fig. 4-20: Details of the stopper moving mechanism.

The pressurized pneumatic cylinder keeps the core in the OUT-BEAM position. The design has been calculated to work with a pressure of 4 bars. This margin allows for an increase of the pressure in case of

friction. When it is de-pressurized, the core falls in the IN-BEAM position. The support plate is damped through shock absorbers on the frame (see Fig. 4-19).

Whenever members of personnel want or are forced to access a downstream area or in fail-safe situations [43], the core needs to move to the IN-BEAM position. The assembly slides in the guiding system vertically.

On the top of the guiding shaft there is an adjustment table for surveying, which supports the tank, as shown in Fig. 4-21.

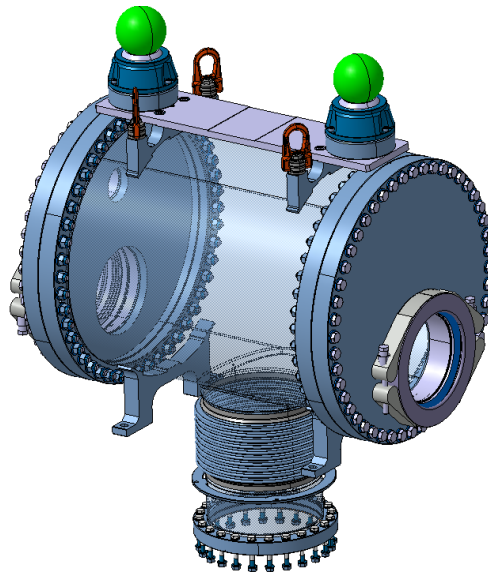


Fig. 4-21: Dedicated vacuum chamber for the beam stoppers.

4.4.2.4 Multitarget

The new multitarget design can be found in Fig. 4-22 and is composed of five different sub-systems:

- i) Aluminium profile chassis.
- ii) X–Y motorization.
- iii) Target arm with a beam screen.
- iv) Camera.
- v) First Plug-in support.

The major change from the first multitarget is the modification of the adjustment system on the target arm. It allows surveys to be more precise and it is faster to align the target. Furthermore, a lower plugin position of the chassis was added in case the entire multitarget has to be removed. The motorization has also changed to better manage the spare pool.

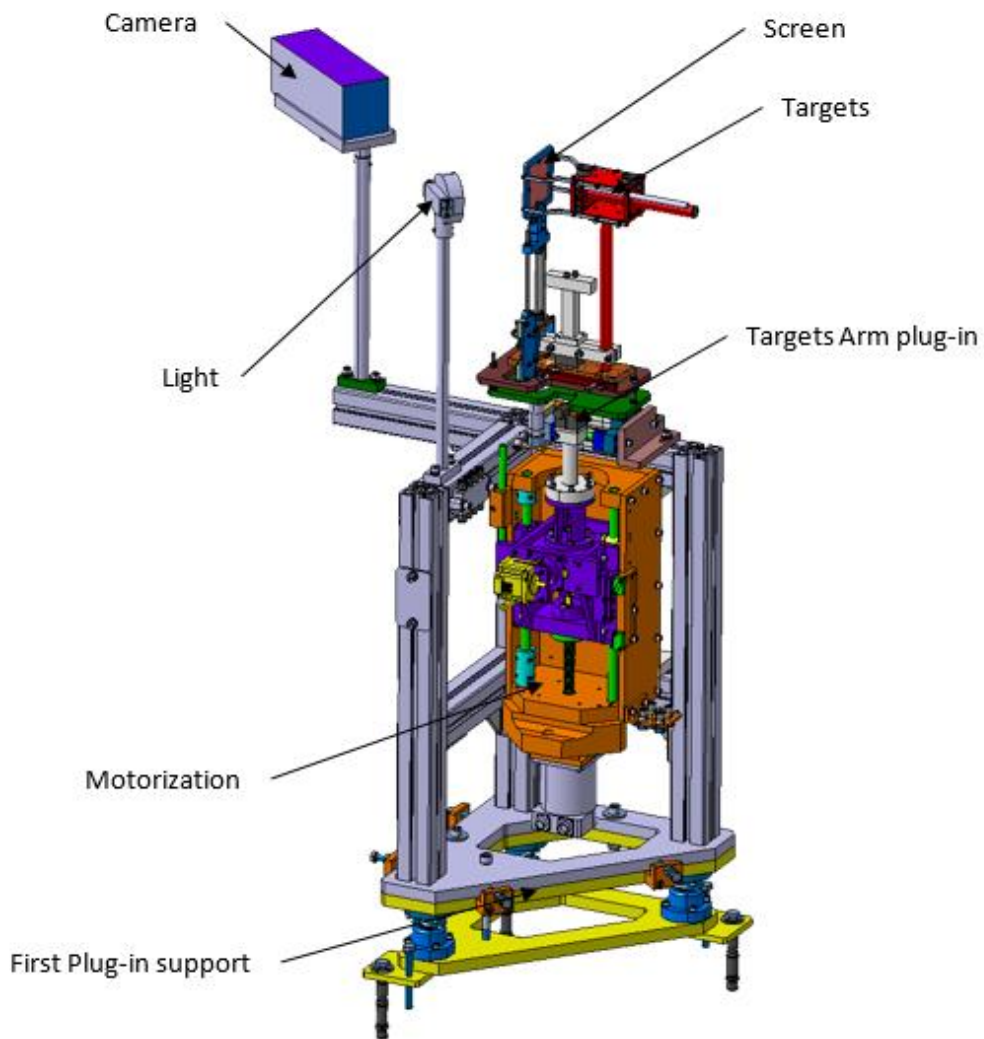


Fig. 4-22: Multitarget new design.

4.4.2.5 East Area integration

In this new configuration (Fig. 4-23), five beam stoppers will be installed on the F61 and another five on the T8 line. This number of stoppers on this line is due to the radiation protection requirements for the beam attenuation and the facility of access to the downstream experimental area. Each secondary beamline is protected by one stopper dump each (T09, T10, T11).

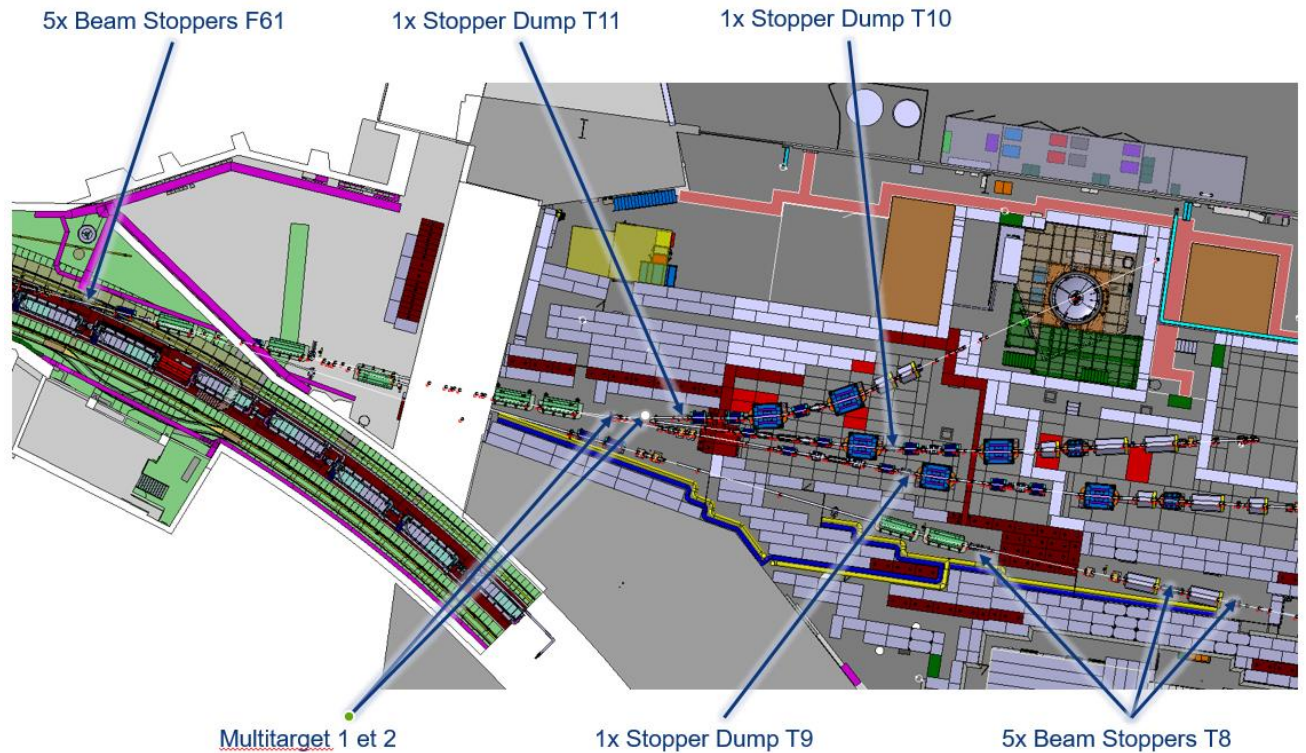


Fig. 4-23: New integration of the beam stoppers, stopper dumps, and multitargets.

4.5 Beam instrumentation

Most of the present beam instrumentation is preserved in the future East Area configuration [46]. The main changes concern their integration into the layout of the new experimental lines. Some old beam profile monitors in the secondary beamlines will be replaced by new ones based on scintillating fibres. New beam loss monitors will be installed along the primary lines F61, T08, and around the two multi-targets. The monitors listed below are classified by main observable.

4.5.1 Intensity measurement and particle counters

The measurement of bunched beam intensity in the transfer lines is performed by fast beam current transformers (BCTF). During slow extraction, where the beam is debunched, the BCTF cannot measure the spill due to the monitor's limited bandwidth (low cut-off frequency), and also due to the low particle flux. Most of the time, beam interacting devices are required in experimental beamlines.

4.5.1.1 Beam current measurement based on gas: BCGAA (formerly named LSD)

The longitudinal spill detection relies on collecting beam-induced ionization photons with nitrogen gas. The electric signal generated by a photo-multiplier (PM) is amplified and sampled. As shown in Fig. 4-24, the plot of the longitudinal spill is displayed on the East Area Vistar for routine check by the operators. Only one device will be kept after the renovation. The monitor's position will be about the same, i.e. 22 m from the extraction point, before F61.MBXHD025 in the new layout (see Table 4-12).

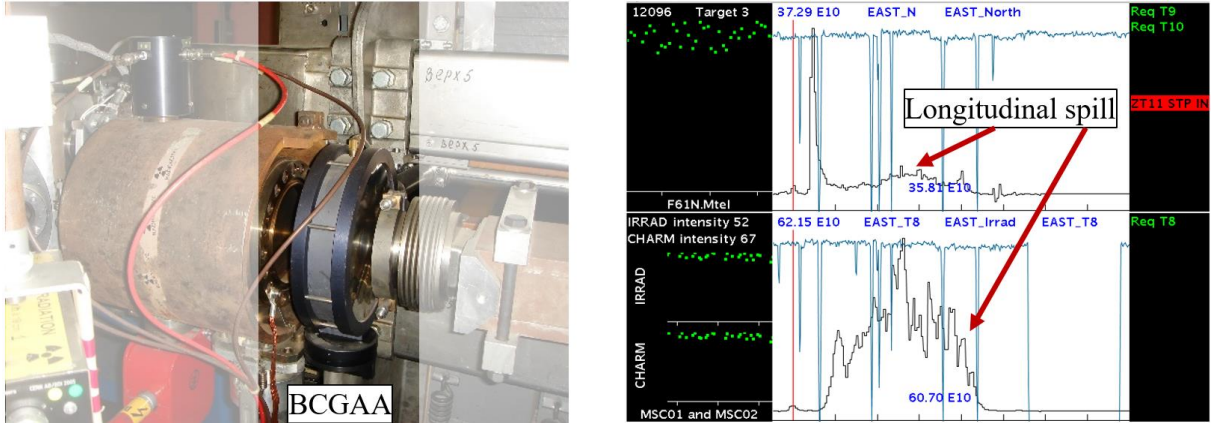


Fig. 4-24: Left: longitudinal spill detector; right: signal from the monitor displayed on EA Vistar.

Table 4-12: Position of BCGAA in the new primary lines.

Line section	Layout component name after LS2	Equipment code
F61	F61.BCGAA023	BCGAA

4.5.1.2 Secondary emission chamber: XSEC / XION

The phenomenon of secondary electron emission from the surfaces of thin metal foils hit by charged particles can be used for particle detection. The so-called secondary emission chambers (XSEC) [44] consist of a stack of plain and polarized hollow thin metal films in vacuum: secondary electrons collected by high voltage electrodes are proportional to the total number of incoming particles. Calibration with a bunched beam (protons or ions) is performed before each run. The comparison of signals from F61.BCTF022 with secondary monitors gives a scaling factor so that the total beam flux and intensity integrated along the spill is deduced.

The argon ionization chambers (XION) use the ionization of argon by particle collisions and collect the electron charge to count primary ion particles. Twenty-one parallel electrodes (5 μ m aluminium foils) are placed in a stainless steel vessel filled with pure Ar gas slightly above atmospheric pressure: eleven of the electrodes are connected to a local high voltage battery supply, whereas the ten charge collecting foils are connected to the output. The ionization counter works with no avalanche amplification and gives a small but reliable output signal that mirrors the intensity. The analogue signal is sent towards a counter (scaler) in the APRON equipment room and is controlled by a front-end software architecture (FESA) class. The beam intensity is read by controls for the SPS experimental areas (CESAR) system.

Few beam monitors can operate in the target zone due to the very high activation level, but XSEC and XION can withstand high levels of radiation. Both are shown in Fig. 4-25, with the figure of merit for the operators displayed in Vistar (red circles).

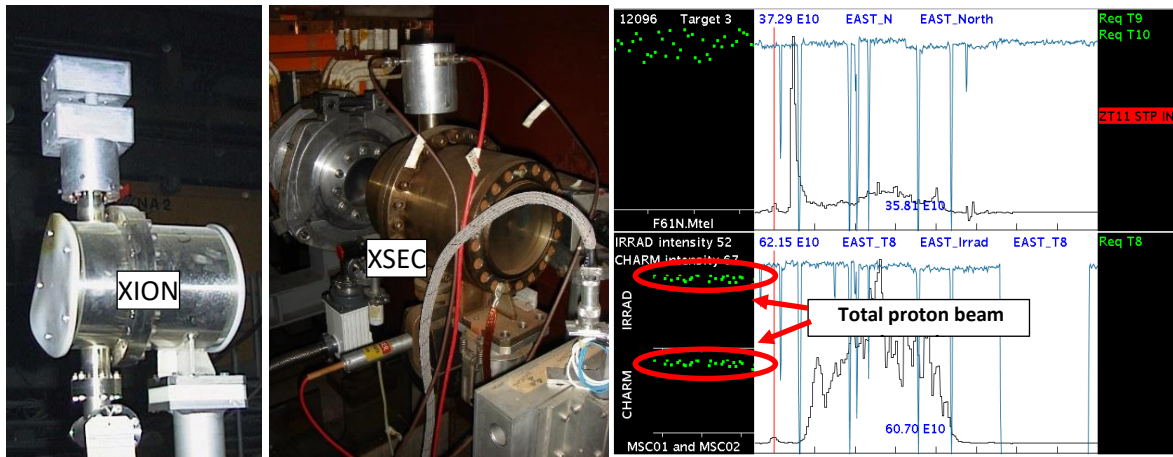


Fig. 4-25: Left: pictures of secondary emission chamber, middle: argon ionization chamber; right: each green dot represents the integrated beam intensity per extraction.

After renovation, all secondary emission chambers will be kept at their current positions in the beamline, except the one in F61, that will be relocated downstream for integration reasons. Like the F62 target, the new target in the F63 line will be equipped with a XSEC. In total, five monitors will be deployed in the new EA layout (see Fig. 4-26). Table 4-13 lists their positions in the extraction line sections and their names in the new layout after renovation.

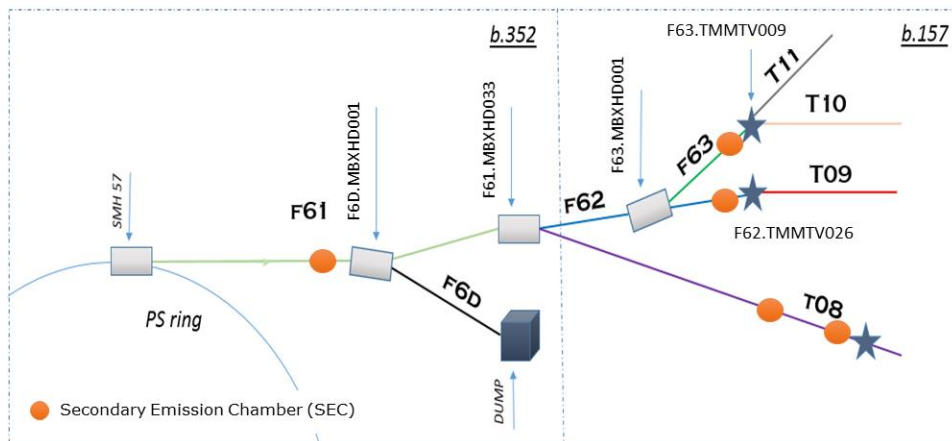


Fig. 4-26: Position of XSEC on the new East Area lines.

Table 4-13: Position of XSEC-XION in the new primary lines.

Line section	Layout component name after LS2	Equipment code	Comment
F61	F61.XSEC023	XSEC	
F62	F62.XSEC022	XSEC	F62 target zone
F63	F63.XSEC008	XSEC	New F63 target zone
T08	T08.XSEC070	XSEC	
T08	T08.XSEC094	XSEC	
T08	T08.XION094	XION	

4.5.1.3 Fast current transformer: BCTF

As mentioned in Section 4.5.1, the monitor F61.BCTF022 is used to calibrate XSEC and XION with bunched beams (see Table 4-14). The current transformer will be kept as it is.

Table 4-14: Position of BCTF in the new primary lines.

Line section	Layout component name after LS2	Equipment code
F61	F61.BCTF022	BCTF

4.5.1.4 Beam loss monitoring (BLM) system

Initially not present in the baseline of the East Area Renovation project, a system to acquire and process the data from 15 BLM detectors spread along the lines has been installed in the East Area, with the scope of observing the beam losses in real time and optimizing the beam process. The new system will be generic and highly configurable. It is based on the ionization chamber (IC) design developed for the LHC that are now widely used in the CERN accelerator complex. Similarly, all the electronics will be of the LHC Injector Upgrade (LIU) type that has recently been deployed for the next run. The technology is reliable, radiation hard, and comes with standard spare parts.

In total, seven BLM detectors will be installed along the primary lines, starting from the PS extraction to the IRRAD and CHARM experimental areas. The beamlines concerned will be F61, F62, F63, and T08 as shown in Fig. 4-27.

Eight additional detectors will be installed in sets of four units downstream of the T09 target (F62.TMMTV026) and the T10/T11 target (F63.TMMTV009) as shown in Fig. 4-28. The idea is to equip each target with a pair of BLMs per plane (horizontal and vertical).

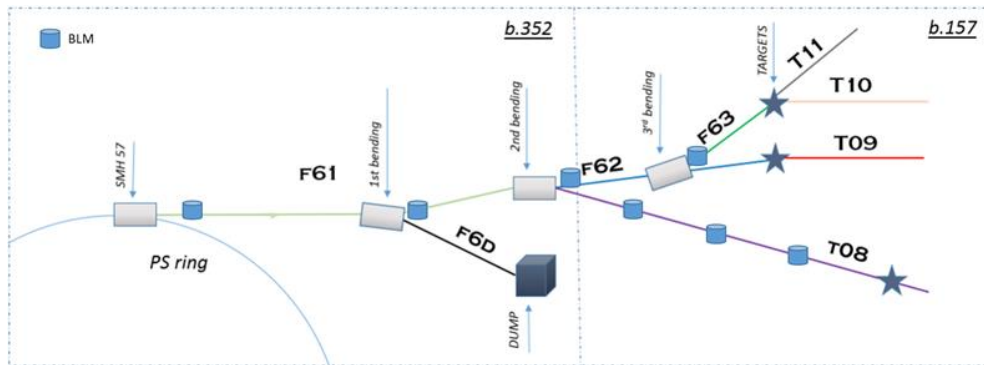


Fig. 4-27: Sketch of BLM detector positions along the primary lines.

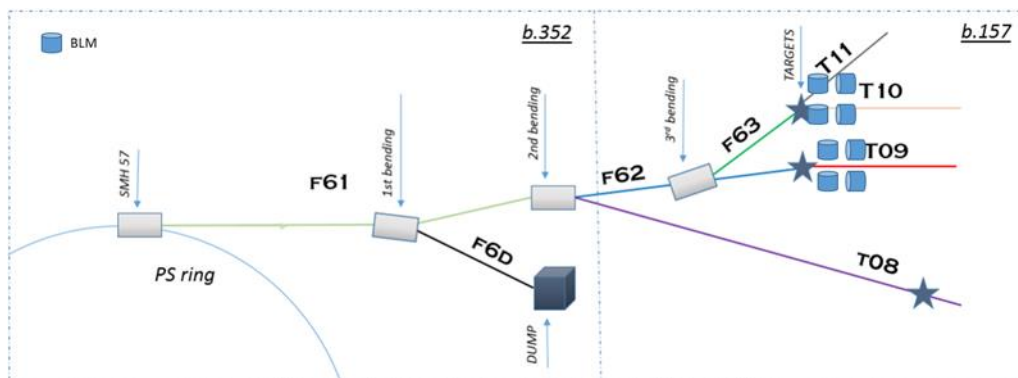


Fig. 4-28: A set of four BLMs will be installed downstream of each target, with the following layout: a couple of units for both H and V planes.

4.5.1.5 Specific particle identification counter based on Cherenkov effect: XCET

Threshold Cherenkov counters are available in some of the East Area beamlines to obtain particle identification information for individual particles in that beamline. The detector is filled with gas that is able to detect particles with speed above the speed of light in the gas. For a certain beam energy, the lighter particles will

have a higher speed. The particles with a speed higher than the speed of light (relativistic particles) inside that particular gas environment will produce Cherenkov light that can be detected by a photomultiplier. The gas pressure inside the detector sets the limit of mass of the particles that can be detected. The beam enters in the detector tube through an entrance window, traverses the tube filled with the selected gas, and exits through the exit window (Fig. 4-29). Inside the top part of the vessel cone, also filled with gas, a mirror deflects the light towards the optical window behind which the photomultiplier is located.

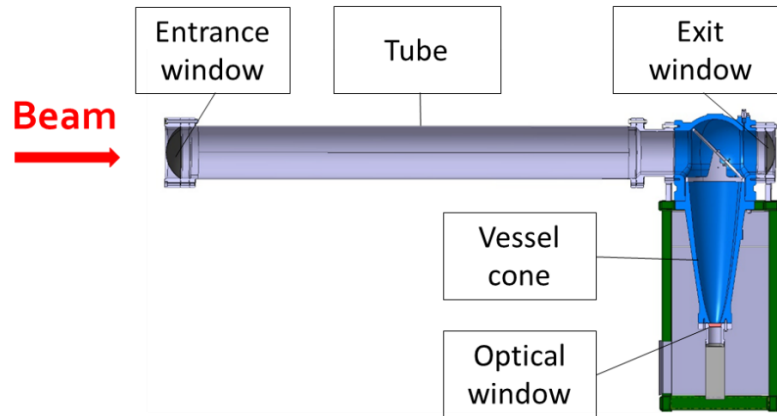


Fig. 4-29: Structure of a Cherenkov counter.

The Cherenkov counters installed in the East Area line consist of a 2.5 m long stainless steel tube with a diameter of 168 mm. The overall desired length should be chosen in accordance with the light efficiency and allowable multiple scattering. Both open ends, the entrance and the exit window of the counter are terminated with 1.4 mm thick aluminium windows. The Cherenkov gases might be selected by the user but should be non-flammable gases, e.g. CO₂, N₂, R218, R134a, etc. to a maximum gauge pressure of 15 bar.

The actual counters are very old instruments, with windows and support structures requiring renovation. Furthermore, the gas pressure is difficult to set precisely and is manually controlled through the old control panel (Fig. 4-32, left). Unlike the North Area, the PM high voltage supply and PM signals are controlled and managed by the users. After renovation, T09 and T10 will be equipped with new pairs of Cherenkov counters. Their respective locations are shown in Fig. 4-30.



Fig. 4-30: Location of the new Cherenkov counters in the T09 and T10 beamlines.

The structure of the new counters (see Fig. 4-31) is similar to that of Fig. 4-29, with a horizontal tube which can be assembled in a modular way depending on the required length. The latter will be filled with either

N₂ or CO₂ gas under an absolute maximum working gauge pressure of 15 bar. When gas exchange is needed, or the chamber is emptied, the detector remains under primary vacuum. More technical information regarding the new counters is available in Table 4-15.



Fig. 4-31: New Cherenkov counter. Left: body; centre: conical part; right: complete assembly.

Table 4-15: Technical details of the four new Cherenkov counters of the East Area.

Line	Beam aperture (mm)	Total length (mm)	Layout name after LS2	Equipment code
T09	159	3 280	T09.XCET044	XCET
T09	159	3 115	T09.XCET048	XCET
T10	159	2 975	T10.XCET040	XCET
T10	159	2 595	T10.XCET043	XCET

4.5.1.5.1 New acquisition chain and gas control interface

The future acquisition chain will follow North Area standards: the analogue signals are sent towards acquisition modules for Cherenkov counters in the APRON equipment room and controlled by a FESA class. The detector settings will be done by CESAR.

The gas supply line will be updated using a new logic and automation for the gas control system based on low-voltage-controlled valves (Fig. 4-32, right).

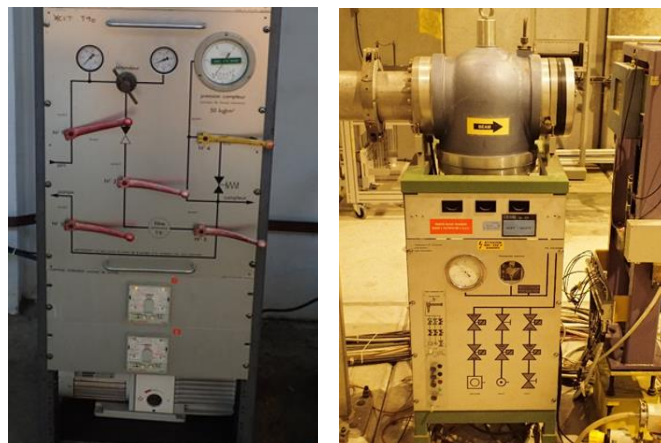


Fig. 4-32: Left: actual manual gas control panel for the counters in the East Area. Right: remote control interface for Cherenkov counters in North Area.

4.5.1.6 Scalers

‘Scalers’ are counter channels from a VME board provided to experiments in groups of four. A large experiment can have up to twenty. Scalers are based on SIS3803 modules located in the beam instrumentation (BI) electronic rack in the APRON barrack. A set of four cables per user barrack will be dispatched.

4.5.2 Profile monitors

The beam profile is affected while crossing different accelerator components: bending magnets, quadrupoles, or radio frequency (RF) cavities. A beam width control is important for the transverse matching between machines and also for the beam spot towards the experiments. During slow extraction, profile monitors can serve as position pick-ups. Under such beam conditions, as with the BCTF, standard beam position monitors are blind due to their limited low-frequency bandwidth. There is a large variety of profile monitors, depending on the particle type, current, and energy.

4.5.2.1 Beam observation monitor with fluorescing screen with scintillating screen and target TV

4.5.2.1.1 BTV with scintillating screen

Following a large upgrade programme undertaken during YETS15-16 to replace the old ‘Marguerites’ stations, proton beam profiles in the PS extraction line F61 upstream of the East Area are now acquired by intercepting the beam with chromium-doped alumina screens and observing the emitted fluorescence with radiation hard cameras. The screen insertion device is made via a vacuum compatible magnetic push-pull system, where bellows are no longer needed. Only the first beam observation monitor with fluorescing screen (BTV) in T08, which is an operational BTV with bellow (see Fig. 4-33), was not in the scope of the upgrade programme.

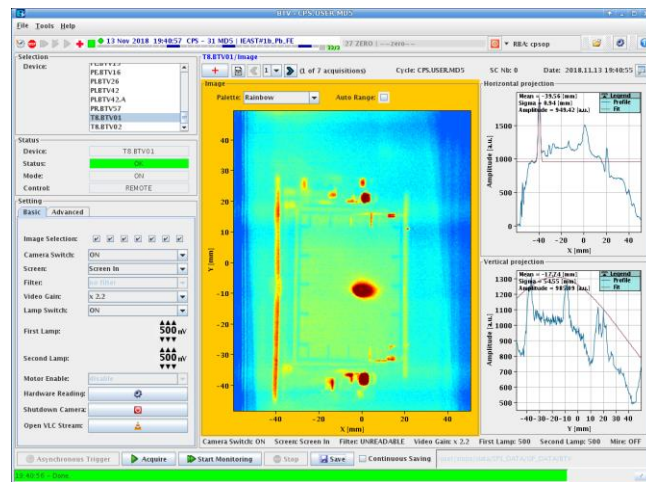


Fig. 4-33: Reference picture from T8.BTV01 during the 2018 ion run.

4.5.2.1.2 Target TV

Besides the secondary emission chamber described earlier, that can operate in a very activated environment, a radiation hard camera is placed upstream of the present F61 target to visualize the beam spot and resteer off-centred beams if needed.

4.5.2.1.3 Layout change during LS2

Only five BTVs out of six will remain in the primary beamlines, with minor changes regarding their positions in the new layout. Currently there are two target TVs, one for the F61 line and one for the CHARM target in the T08 line. After LS2, a third TV will be implemented for the new target in the F63 line. Their positions are schematically represented in Fig. 4-34. Some technical details and new layout names can be found in Table 4-16.

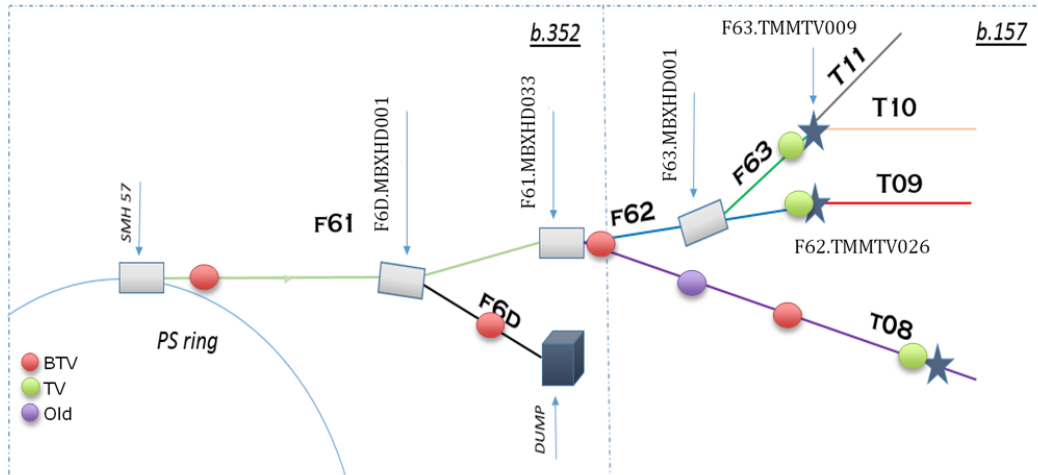


Fig. 4-34: Position of the BTVs in the new layout.

Table 4-16: Technical details and new layout name of BTVs and target TVs after LS2.

Present name	Layout name after LS2	BTV type	Equipment code
F61.BTV01	F61.BTV012	PSZBTVMC (screen 100 mm)	BTV
F61.BTV02	Spare	PSZBTVMC (screen 100 mm)	BTV
F61.BTV03	F62.BTV002	PSZBTVMC (screen 140 mm)	BTV
F61D.BTV01	F6D.BTV010	PSZBTVMC (screen 100 mm)	BTV
F61S.BTV01	T8.BTV020	PSZBTVMC (screen 100 mm)	BTV
ZT8.BTV01	T8.BTV035	Old BTV design, with below	BTV
F61N.BTV01	F62.TMMTV026	Target TV	TMMTV
New	F63.TMMTV009	Target TV	TMMTV
ZT08.BTV02	T08.TMCRT097	Target TV	TMCRT

4.5.2.2 Multi-wire proportional chamber in T08 Line: XWCM

This monitor is mainly used during the commissioning phase of secondary beamlines in the experimental areas. Its typical particle flux range is 10^5 to 10^{11} p/s. The main observables are transverse beam profiles as well as beam position (see Fig. 4-35).

The detector consists of a set of $40 \mu\text{m}$ stretched tungsten wires, having a 1 mm spacing. The plan is placed between a couple of aluminium foils in a housing containing an equal mix of CO_2 and Ar gas. A high voltage is applied between the foils (cathode) and the wires (anode). The latter collects ionization-induced electrons amplified by avalanche effect. The charges from each wire are integrated during the extraction time. The beam profile is obtained by reading the integrator output voltage from each wire, as shown in Fig. 4-36.



Fig. 4-35: A multi-wire proportional chamber in the North Area (XWCA 021 492).

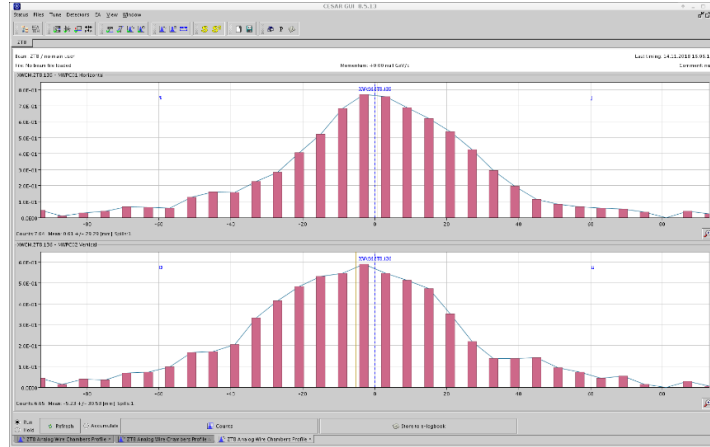


Fig. 4-36: Beam profiles from ZT08.XWCM135 during the 2018 ion run.

This monitor is operational and will be kept without consolidation. Only the layout name will change (see Table 4-17).

Table 4-17: Position of XWCM in the new primary lines.

Line section	Present name	Layout component name after LS2	Equipment code
T08	ZT08.XZCM135	T08.XWCM103	XWCM

4.5.3 Scintillator-based detectors

A scintillator is an organic or inorganic material which emits photons following the excitation of atoms and molecules by radiation (γ or particle radiation including neutrons and neutrinos). The material exists in the three matter phases: solid, liquid, or gas. Scintillators are widely used in secondary beamlines as a multi-purpose monitor, for triggering, or particle identification by pulse height analysis. Other possible applications are light guide, wavelength shifter, calorimeters, or time of flight counters thanks to their very fast response time.

4.5.3.1 Particles counters and triggers: XSCI

Plastic scintillators are currently installed in the East Area as particle counters or triggers. T09 is equipped with a pair of scintillators, while T10 and T11 have only one. PMs with high voltage for light amplification and output signal are connected to a dedicated acquisition module in the APRON equipment room, and controlled by a FESA class. The present detectors are kept, with minor displacement in the new layout. T10 will get a second detector. Their positions and new layout name are listed in Table 4-18.

Table 4-18: Position of XSCI in the new primary lines.

Line	Layout name after LS2	Equipment code
T09	T09.XSCI041	XSCI
T09	T09.XSCI050	XSCI
T10	T10.XSCI036	XSCI
T10, new	T10.XSCI044	XSCI
T11	T11.XSCI022	XSCI

4.5.3.2 Scintillating fibre monitors: XBPF

The experimental beam profile fibre monitor (XBPF) [45] is a scintillating fibre detector recently developed at CERN for the measurement of the profile, position, and intensity of secondary beams. The physics principle of particle detection with scintillating fibres relies in the creation of scintillation light, due to the passage of a charged particle, and the transmission of this light inside the fibre by total internal reflexion. The XBPF is

composed of 100 or 200 scintillating fibres (depending on the size of the monitor) of 1mm thickness and square cross-section. The fibres are packed together along one plane, forming the active area of the detector that stands in front of the beam (Fig. 4-37, left). The light from every fibre is read out on one end by an individual silicon photomultiplier that allows one to know which fibre has been activated and to subsequently measure the profile, position, and intensity of the beam. A mirror glued on the non-read-out end of the fibre reflects back the light travelling in that direction along the fibre, thus increasing the total light signal reaching the photomultiplier.

The XBPF has been designed to be vacuum compatible, which removes the need for vacuum windows, therefore helping to reduce the material budget of the beamline. The photodetectors are located outside vacuum, with the fibres exiting via a feedthrough based on an innovative gluing technique that guarantees the necessary leak tightness. The vacuum tank of the new detectors has a modular design that allows two XBPF to be hosted for the simultaneous measurement of the horizontal and vertical profiles of the beam (Fig. 4-37, right).

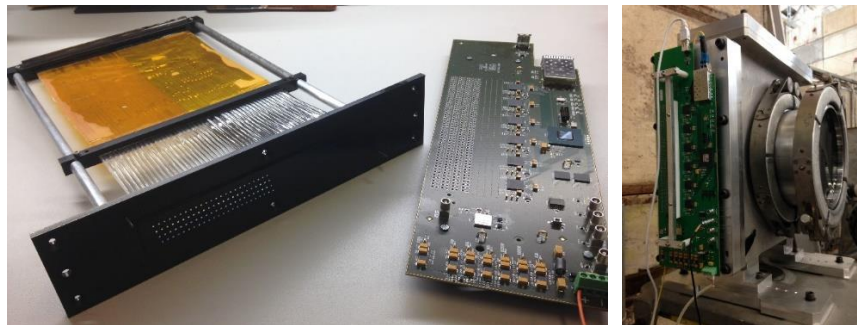


Fig. 4-37: Left: XBPF on the left and front-end board with the 192 SiPMs on the right. Right: vacuum tank of the XBPF during installation, with a front-end electronics board in place.

4.5.3.2.1 New detectors after LS2

These three aging gaseous wire chambers (XDWC) in each of the secondary beamlines, which can no longer provide accurate profiles in all ranges of intensities, will be upgraded by dual-plane scintillator fibre monitors. Table 4-19 summarizes the changes and the new layout names.

Table 4-19: Upgrade of beam profile monitors after LS2.

Line	Changes after LS2	Equipment code	Comment
ZT09	Removed	XDWC	Storage
ZT10	Removed	XDWC	Storage
ZT11	Removed	XDWC	Storage
T09	T09.XBPF041	XBPF	New, 10 cm × 10 cm
T09	T09.XBPF050	XBPF	New, 10 cm × 10 cm
T10	T10.XBPF045	XBPF	New, 10 cm × 10 cm
T11	T11.XBPF022	XBPF	New, 20 cm × 20 cm

To keep the versatility of the new experimental lines, the XBPF tanks will not be pumped down, but left under atmospheric pressure.

4.5.3.2.2 Acquisition chain and cabling

The Beam Instrumentation (BI) group will produce the front-end boards (one per plane). On the back-end side, a VFC-based acquisition board developed by BI for its applications will be used. The transmission between them is performed via optical fibres.

4.6 Survey systems

Due to beam optics requirements, the correct positioning and alignment of all beamline components is mandatory. The future configuration of the East Area will follow the survey requirements in terms of layout [46][47] but also the CERN standards in terms of alignment.

All buildings where the new beamlines will be installed were scanned in three dimensions to do a comparison with the integration model. A difference of 30 mm was found between the PS floor and the East Area Building 157 floor. This height difference will be compensated in Building 157 with the beam equipment supports.

4.6.1 Networks

Before the alignment of the components, a reference network of precise points will be done all around the areas. The positions of these points will be uploaded on the survey database and will be used later to align the equipment.

The network area includes Building 352 and all the beam areas in Building 157 as shown in Fig. 4-38. In order to establish the point network between Buildings 352 and 157 there will be a hole in the separation wall between these buildings. The same procedure must be applied for all internal walls of Building 157 between the closed zones. The network needs to be determined before dismantling the main components already installed in the East Area.

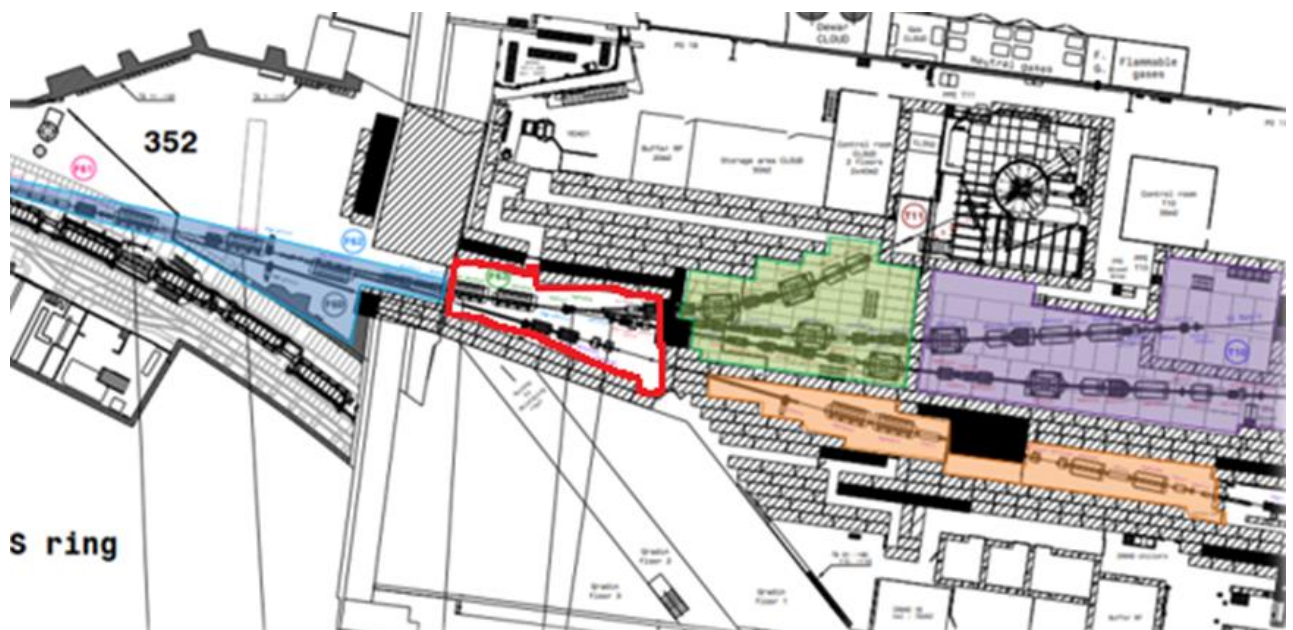


Fig. 4-38: Building 352 (in blue), primary area (red), mixed area (green), T8 area (orange), secondary beam area (purple).

4.6.2 Fiducialization

Each component to be aligned will have two survey fiducials (usually spheres) on top of it, indicating the entry and exit of the element ('Entrée+Sortie' E + S) plus a tilt surface to measure the angle of the element. The two fiducials installed on the components should leave enough space to put the measuring system on top (min. 50 cm).

In order to align each component with respect to the network, a fiducialization step has to be performed before installation. The fiducialization is a procedure where the relative positioning between the two survey fiducials (E+S) is measured with respect to the theoretical beam axis of the component. The fiducialization is a procedure done before installation. The values coming from the fiducialization step give the geometry of the

component. These values are saved in the Geode database and the CERN Coordinate System (CCS) is calculated for each component.

4.6.3 *Ground marking*

Once the network is installed in the area, the ground marking of the theoretical beam axis is done. The beamline is calculated starting from a MADX file of the beamline. The line is also inserted in the database Geode. For each component, the E + S references will be also marked on the ground. The theoretical beamline serves as a reference also for others services (cabling, handling, cooling and ventilation, support installation, transport).

4.6.4 *Alignment*

Once the fiducialization for the components and the ground marking is done, the installation and alignment of the beamline equipment can then be done. The network is used as reference for the measurements and the alignment is done following the beamline optic coming from the methodical accelerator design (MADX) file saved in Geode. There are two steps of alignment: the first consists in the alignment of the supports and the second is the alignment of the components. Depending on the type of support and the components used, the alignment methodology is different.

The standard supports are positioned according to the ground marking. The adjusting table of the support is regulated up to the desired position and then the component is placed on top. The survey fiducials on each component are measured using a laser tracker and an optical level; also the roll angle is measured using an inclinometer. The position of the components is cross-checked on the database.

In the primary area, beamline components will be installed on plug-in supports, which will suppress the need for alignment intervention in the future to reduce the exposition of surveyors to ionizing radiations. For this area, the fiducials are directly installed on the supports that are aligned following the standard procedure. The beamline components will be prepared outside the primary area and the final alignment will be ensured by the plug-in system (based on metallic jacks) without further need for intervention.

4.6.5 *Smoothing*

The smoothing is the final step of the alignment procedure and is usually done just before beam commissioning. All components are measured in the vertical and radial directions and the data are used to create a smoothing beam curve. All components should be on the curve; if a component is out of the tolerances, it will be realigned.

4.7 **Machine interlocks**

4.7.1 *Introduction*

The interlock systems constitute a vital part of the machine protection systems and protect the different machine elements from damage. In the case of the East Area, a machine interlock system for the protection of the resistive magnets is in place. Under the mandate of the EA Renovation project, it was decided to replace this legacy interlock system, as part of the renovation of the magnets, with a standardized warm magnet interlock controller (WIC) system. As a generic solution to the interlocking requirements existing throughout the CERN complex, the functionality of the WIC system for the East Area will be identical to the other WIC systems already in operation in the CERN Accelerator Complex or other experimental areas (e.g. Elena). No other machine interlock systems will be installed in the East Area and for this reason, no equipment will be able to automatically stop the beams by hardware.

4.7.2 Warm magnet interlock controller system

4.7.2.1 Warm magnet interlock controller system overview

The warm magnet interlock controller (WIC) system is in charge of protecting the resistive magnets against overheating [48]. It is a PLC-based system. The central processing unit (CPU) of the PLC is the central controller and, in case of overheating of one of the magnets protected, will send the fast abort signal to the corresponding power converter that powers the magnet. The temperature of the magnets is compared against a pre-set limit by several thermo-switches installed on the magnet coils or busbars and the flow of the cooling system of the magnets is also monitored by the WIC. In the case that abnormal conditions are detected, the WIC will react to protect the magnets. A schematic figure depicting the WIC system can be found in Fig. 4-39.

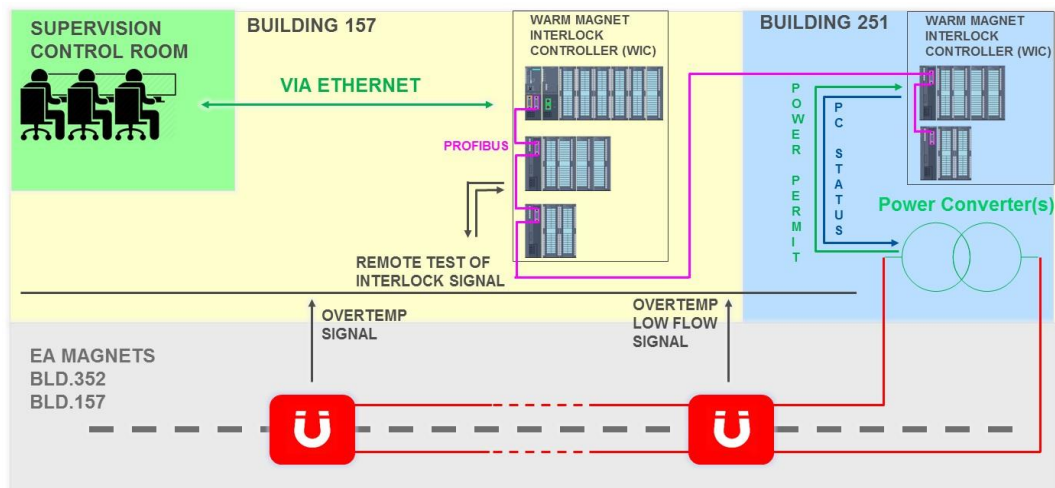


Fig. 4-39: Simplified layout of the WIC system for the East Area.

The WIC system is highly reliable and assures the minimum downtime due to failures of the protection system. The system was designed as a standard solution to be deployed CERN-wide. In the case of the East Area, there is no link to the beam interlock system.

The WIC uses a generic software program and a homogeneous hardware solution to adapt the specific interlock requirements to the existing layout. The layout is described within a database (including magnet names, input and output addresses, power converters, interface types, and others). The specific information for each installation is extracted in different configuration files that will be used to define the system in accordance with the project requirements.

4.7.2.2 The WIC layout for the EA

The dedicated WIC to protect the 58 magnets located along the F61 line, in the primary and secondary areas of the EA will be installed during LS2. The system will have two dedicated racks (Fig. 4-40), one for the control and the acquisition of the magnet signals located in the Apron room (157/1-009), and another located in Building 251 to control the 61 power converters. The details of the WIC configuration of the EA can be found in Ref. [49].

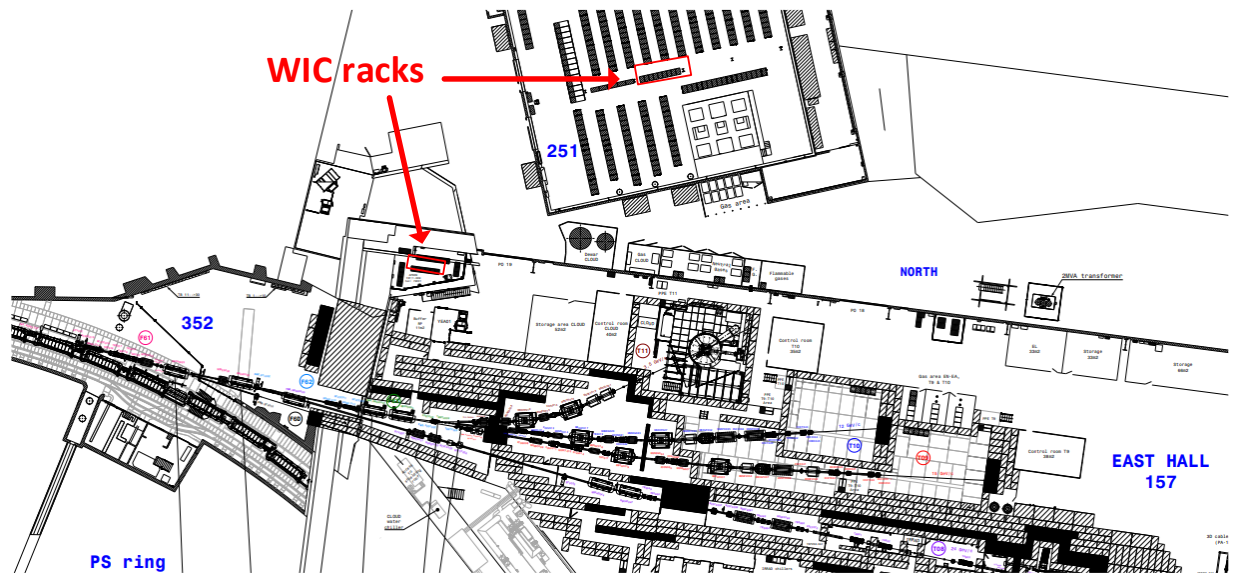


Fig. 4-40: Layout of the East Area with the location of the two WIC racks.

4.8 Beam controls

4.8.1 Upgrade of the infrastructure

The control infrastructure provided by the Controls Group (BE-CO), Beams Department, will be upgraded for the EA as part of the overall initiative to upgrade the hardware and software components during the long shutdown LS2. New pulse repeaters (for the distribution of pulses) and new a general master timing (GMT) distribution to all front-end computers (FECs) will be installed as well as new hardware components, replacing the ageing components dating from 1980 with enhanced remote monitoring and diagnostics of the whole distribution chain. New full digital distribution system (Matrox digital decoders) will replace the old analogue video distribution system (CATV) (Fig. 4-41).

All FECs used in the East Area had to be upgraded to FESA3 version 7 and to CENT-OS7 by 1 January 2020; this date corresponds to the official end of life milestone for all BE-CO legacy components [50]. The upgrade is under the responsibility of persons in charge of the FEC and of the FESA classes.



Fig. 4-41: New video distribution system.

4.9 Collimators

4.9.1 General description

The collimators are devices composed of internal jaws that are moved according to the operation requirements to clean the beam by removing stray particles and protecting downstream equipment, shielding it from beam trajectory errors. The internal aperture of a collimator can be used to define the range of beam energy, reduce the beam intensity (acceptance collimator), find the beam by scanning the aperture, divide particles of different types, and clean the beam disturbed by other collimators upstream.

The T09, T10, and T11 secondary beamlines are equipped with obsolete PS-type collimators, poorly documented for their mechanics and with replacement parts hard to find. In addition, the current collimators are also incompatible with computer control. Mechanical failure is the main issue with the beamline collimators such as jammed positioning mechanism, broken ribbon, or faulty ball bearings or potentiometer. Electrical failure is also likely including motor fault, impossible data reading, problems with electronics given by the high radioactive environment, etc.

It is therefore proposed to replace the old East Area collimators by four 4-jaw collimators (XCHV) taken from the North Area spare collimators [51] and three new 2-jaw collimators (XCSV and XCSH). The spare collimators of the North Area can be re-used provided that a thorough refurbishment is completed and validated by commissioning tests. The new collimators control system will be done via FESA classes, logged and controlled by CESAR and TIMBER.

By using XCHV and XCSV/H, collimators already used in the North Area it will be possible to make the device types and controls used at CERN in the experimental areas more uniform, easing the standardization and classification of equipment and control systems.

In total, 7 new collimators will be installed: 3 XCHV for T09, 1 XCHV, 1 XCSH, and 1 XCSV for T10 and 1 XCSH for T11 (see Fig. 4-42). In addition to these collimators, a new fixed collimator, the XTCX, will be added at the beginning of the T09 line during LS2 (see Section 4.9.4).



Fig. 4-42: Location of the new collimators in T09, T10 and T11.

4.9.2 XCHV collimator design

The XCHV collimators have four internal jaws made of steel (in grey in Fig. 4-43) of which two are moved along the horizontal direction and two along the vertical one. Every jaw is motorized and the position is controlled by a linear potentiometer (Fig. 4-44).

The external structure of the collimator is a vacuum vessel that is connected upstream and downstream with the vacuum beam chamber.

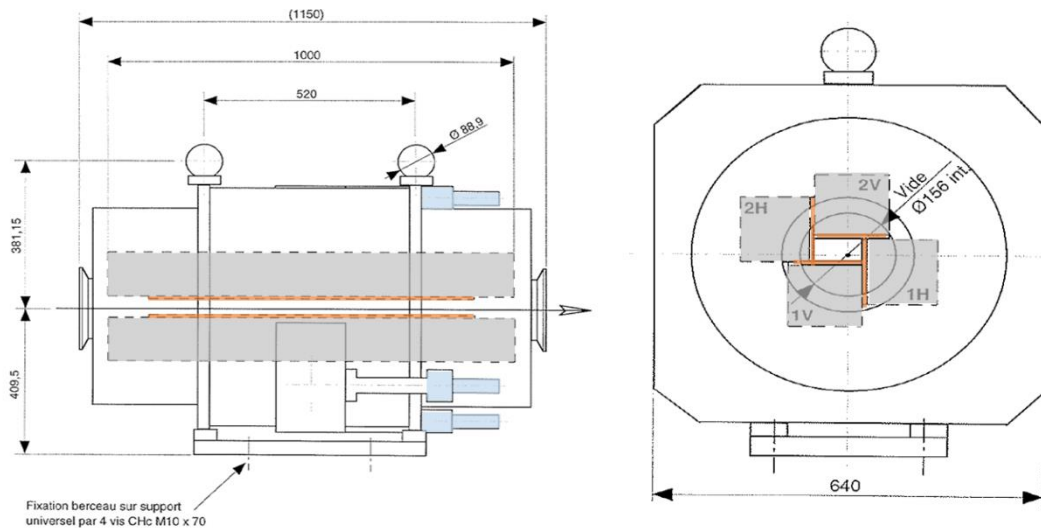


Fig. 4-43: XCHV collimator drawing a longitudinal view and upstream view of the open collimators with jaws.

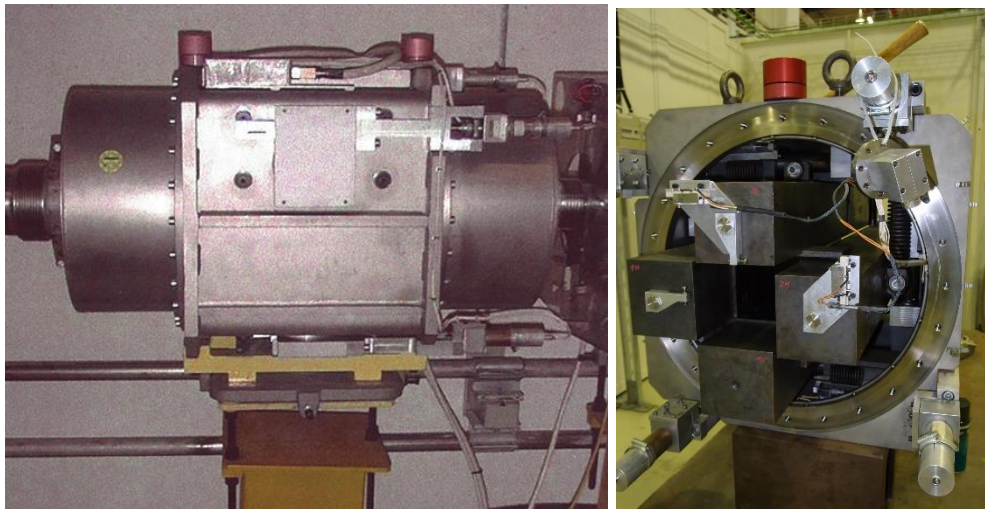


Fig. 4-44: Longitudinal view and downstream view of an open collimator with the jaws and motors.

4.9.3 XCSV-XCSH collimator design

The XCSV and XCSH collimators (Fig. 4-45) have two internal steel jaws that are able to move horizontally (XCSH) or vertically (XCSV) driven by a DC motor and their position is controlled by a linear potentiometer. Each jaw is moved by a motor operating in DC. Two micro-switches are mounted externally to indicate the end of the outer movement and a third micro-switch is installed internally in common with the two jaws to avoid collisions between them.

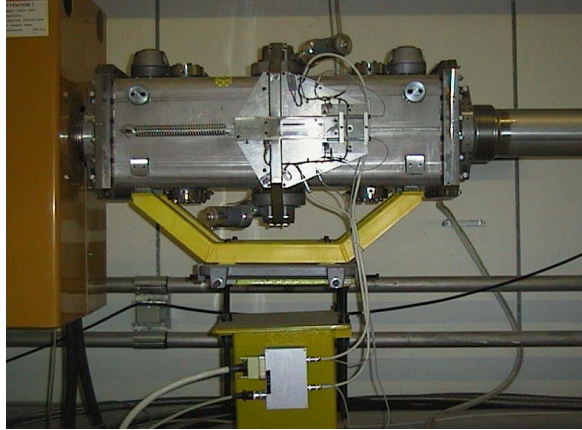


Fig. 4-45: Longitudinal view of a XCSV or XCSH collimator.

4.9.4 XTCX collimator

The XTCX (TCX stands for ‘target collimator experimental areas’) is a beam collimator that serves to protect the facilities placed after the target [51]. It is designed to withstand primary beam intensities. It is composed of an iron block mounted on an aluminium frame. The iron block permit absorption of the beam with a variable momentum spread in order to transmit only the wanted secondary beam with a specific central momentum. The XTCX is located on T09, just after the target (Fig. 4-46). No vacuum chambers pass through the XTCX. The beam passes through the air and comes back through a vacuum chamber just after the XTCX, passing through a 0.1 mm thick aluminium window. It is a passive component without water cooling. Design details can be found in Refs. [52] and [53].

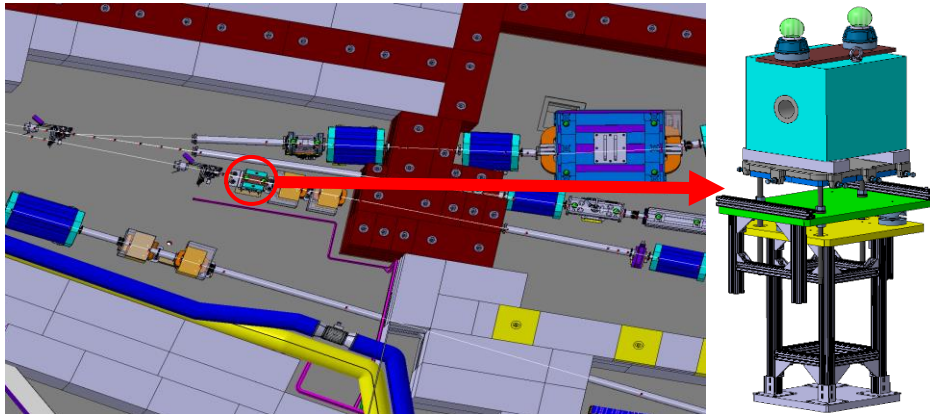


Fig. 4-46: Location of the XTCX in the T09 line.

4.10 Radiation shielding

4.10.1 Facility parameters

The beam parameters that were used for the design of the shielding were taken from Ref. [54]. The East Hall receives a slowly extracted proton beam from the CERN PS with a beam momentum of 24 GeV/c with up to 5×10^{11} protons per pulse and a maximum average beam intensity of 6.7×10^{10} protons per second. Theoretically, up to 6 spills per supercycle of 45.6 seconds can be sent to the East Hall, up to 3 spills per supercycle for T09, and up to 3 spills per supercycle for T10, with 3.3×10^{10} protons per second for each target.

Accounting for the number of days of operation per year and machine availability, the nominal annual number of protons is 3.3×10^{17} protons per year and the maximum annual number of protons is 10^{18} protons per year.

4.10.2 Radiation protection requirements

The shielding of the East Area primary zone has to be designed so that the radiological area classification [55] for the East Hall is respected. Being classified as a Supervised Radiation Area, this means that the ambient dose equivalent rates should be below $3 \mu\text{Sv/h}$ for the control rooms inside the East Hall and less than $15 \mu\text{Sv/h}$ (low occupancy area) at 40 cm outside the shielding walls for the maximum average beam intensity of 6.7×10^{10} p/s, at locations accessible during beam operation. In addition, the ambient dose equivalent rates should be below $2.5 \mu\text{Sv/h}$ outside of the hall for the maximum average beam intensity. These requirements mean that all shielding passages (access chicanes, ventilation ducts, cable ducts) have to be designed in an optimized way.

In addition to compliance with the limits of the radiological area classification, the shielding has to be designed so that the ambient dose equivalent rates are well below the corresponding radiological area classification limits at the most important locations, e.g. the control rooms, for optimization reasons. The shielding also has to be designed so that the annual effective dose to the members of public, combined from prompt radiation (sky shine) and from releases to the environment, is less than $1 \mu\text{Sv}$ for the nominal annual number of protons on the targets.

The design of the shielding tries to make use of as many existing concrete and iron shielding blocks as possible. The design has to take into account the fact that there is limited space due to the already existing facilities in the rest of the East Hall. Monte Carlo simulations were performed with the FLUKA [56][57] code to estimate the prompt ambient equivalent dose rate levels for East Area Primary Zone.

4.10.3 PS - primary ring zone

The shielding in the PS extraction towards the East Area Primary Zone, was placed to protect persons in the Primary Zone during accesses from beam losses in the PS. Three loss point locations have been studied for two beam loss scenarios.

The first loss scenario is a continuous loss in the PS. After discussion with the Operation Group (BE-OP), a 3% loss of all beams injected in the PS was taken into consideration. Being driven mainly by the SFTPRO beam, 4 cycles per supercycle with 2×10^{13} protons per cycles for the SFTPRO beam have been assumed. In order to estimate the continuous loss close to the PS extraction towards the East Area Primary Zone, this intensity was scaled with the ratio of the sum of the residual dose rates in PS sections 61 to 71 compared to the sum of the residual dose rates in the full PS ring based on radioprotection (RP) survey data. The resulting continuous loss rate was rounded up to 5×10^9 protons per second.

The second loss scenario was to take into account the full beam loss of one SFTPRO cycle, i.e. 2×10^{13} protons.

The simulation results for the 3 loss point locations were normalized with these two loss scenarios and the ambient dose equivalent rates and ambient dose equivalent were investigated to design the shielding around the F61 beamline leading to the East Hall and to implement it accordingly [58]. The final design of the shielding, after the above mentioned studies, around the F61 beamline can be found in Fig. 4-47. The ratio between the dose rate at the location of the dose monitor PAXP502 (entrance of Building 352) and the dose rate at the beginning of the Primary Zone will be used to ensure proper area monitoring of the Primary Zone by adapting the dose rate alarm threshold of PAXP502 if needed.

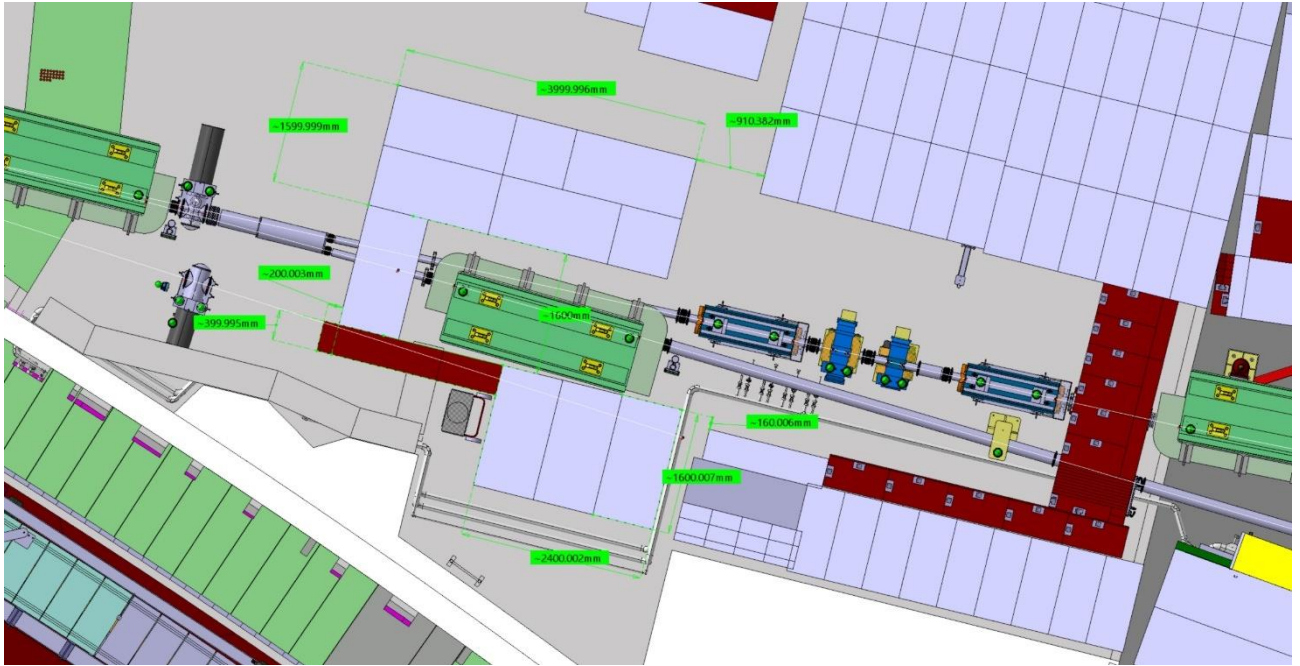


Fig. 4-47: PS – Primary Zone, in CATIA model.

4.10.4 The Primary Zone

Simulations [59] have been performed with the FLUKA code for the shielding of the Primary Zone. The shielding is presented in Fig. 4-48. The design of the access chicane towards the primary zone was based on the simulation studies as well as the shielding towards the access point on the south side.

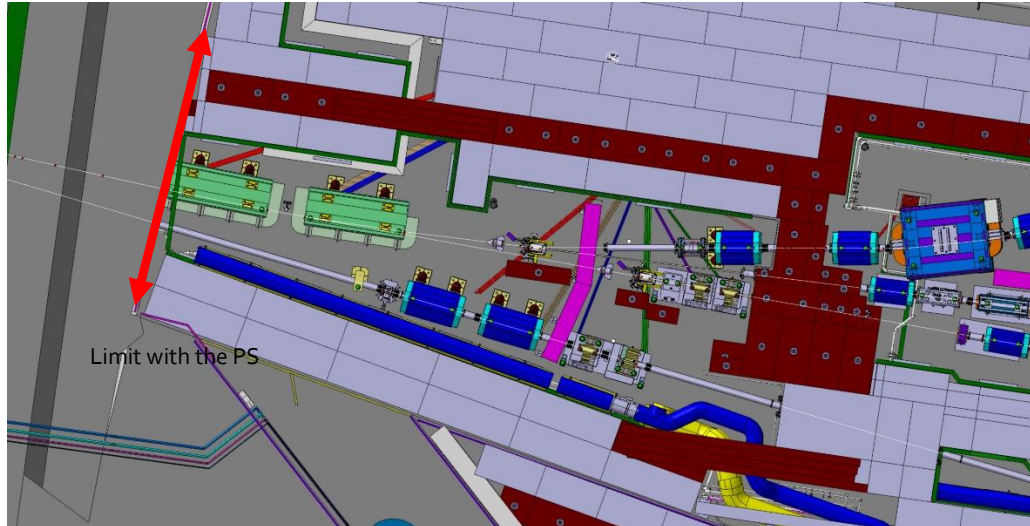


Fig. 4-48: Top view of the primary without the roof.

The shielding of the roof above the Primary Zone starts at 3.2 m height of the Primary Zone room and consists of 0.8 m of concrete, 0.8 m of cast iron, and 3.2 m of concrete (up to 8 m from the floor level). The roof shielding covers all of the Primary Zone area and continues until the access doors (Fig. 4-49). The optimization of the shielding on the edges will be based on the simulations by FLUKA.

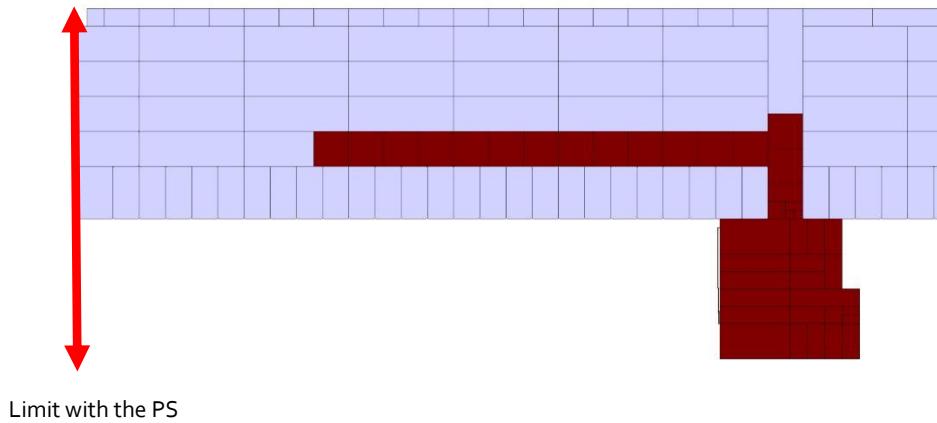


Fig. 4-49: Vertical cut of the primary area roof.

4.10.5 *Beam dump for the F62 and F63 beamlines*

The beam dump design is very important because it affects the prompt and residual radiation values upstream and downstream of it.

Several scenarios were studied for the dump between the Primary Zone and the mixed zone, taking into account the prompt and residual radiation. The dump optimization has yielded a significant reduction of the prompt dose rate downstream and on the roof, leading to a reduction of shielding thicknesses. The most suitable dump configuration was chosen, taking into consideration the construction, radiation, and cost constraints. The optimized configuration of the dump is shown in Fig. 4-50, with a tungsten block of 20 cm × 20 cm × 40 cm at the T10 line, see Fig. 4-51, inserted in the dump 10 cm downstream of the front face of the dump and centred around the beam. The additional shielding for the T09 beam dump is shown in Fig. 4-52.

The residual dose rate optimization in the primary zone will be done by installing a movable shielding, mounted on rails, to cover the two impact points of the beams T09 and T10 on the dumps and centred around the beam, during accesses.

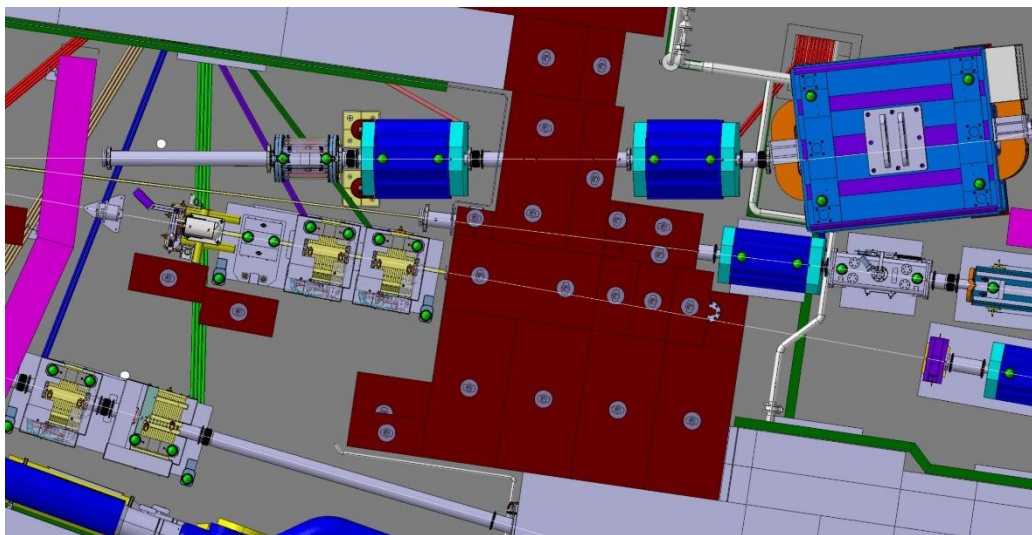


Fig. 4-50: Optimized configuration of the dump in CATIA model.

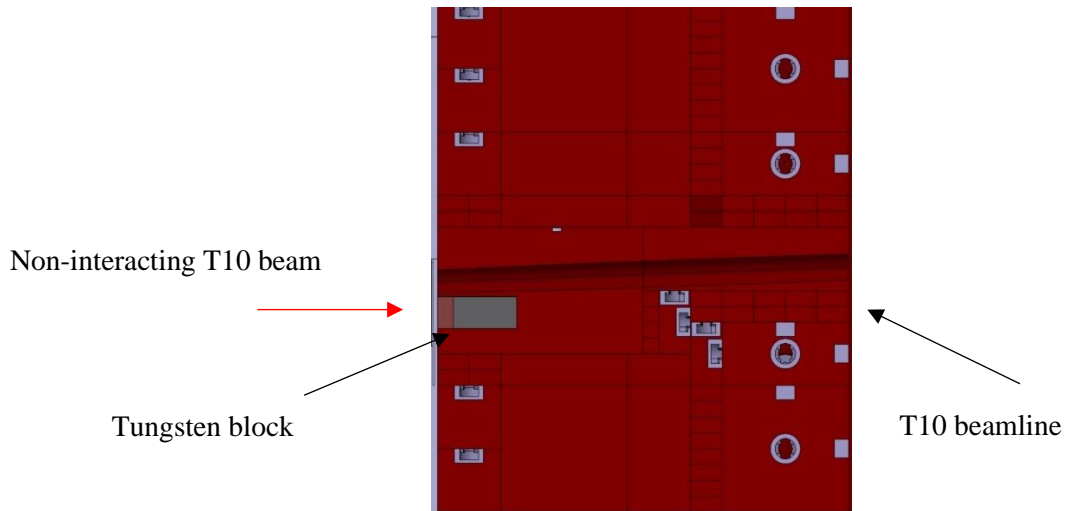


Fig. 4-51: Tungsten block of 20 cm × 20 cm × 40 cm at T10 beamline.

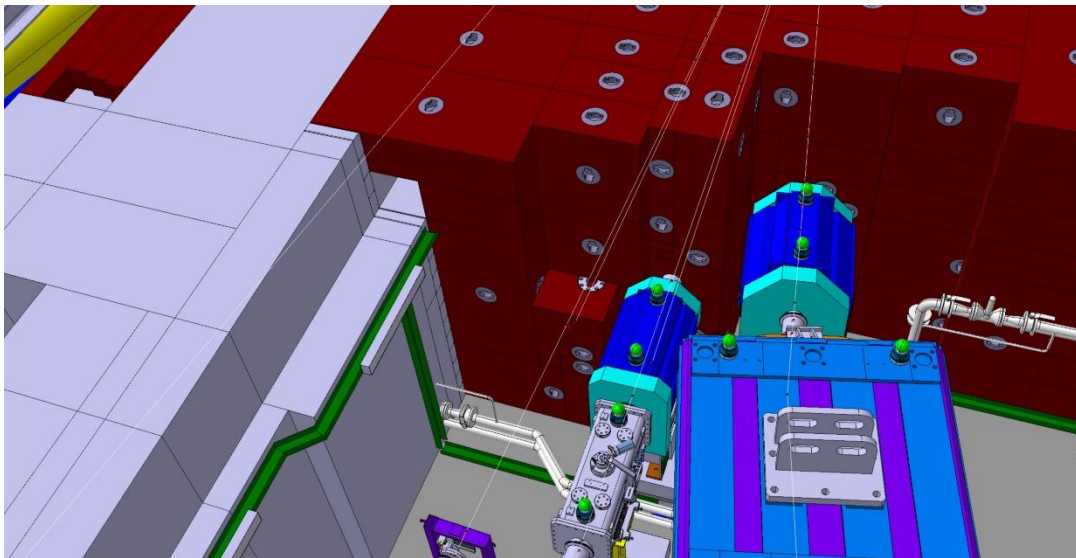


Fig. 4-52: T09 side of the beam dump.

4.10.6 *Mixed zone*

The shielding of the mixed zone, see Fig. 4-53, was designed taking into account the radiation derived from the dump and the beam losses of the secondary beams transported in T09, T10, and T11.

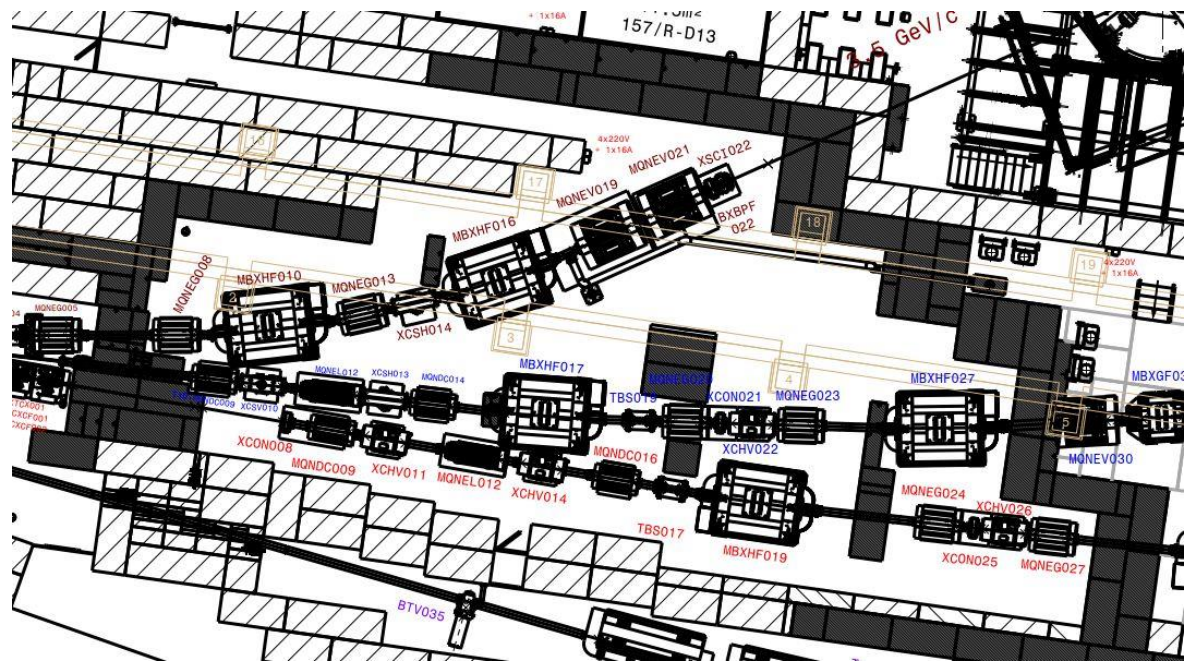


Fig. 4-53: Mixed zone.

The shielding of the roof above the mixed zone has been defined by FLUKA simulations. It starts at a 3.2 m height of the mixed zone and consists of a 3.2 m to 4.4 m height of concrete shielding (Fig. 4-54).

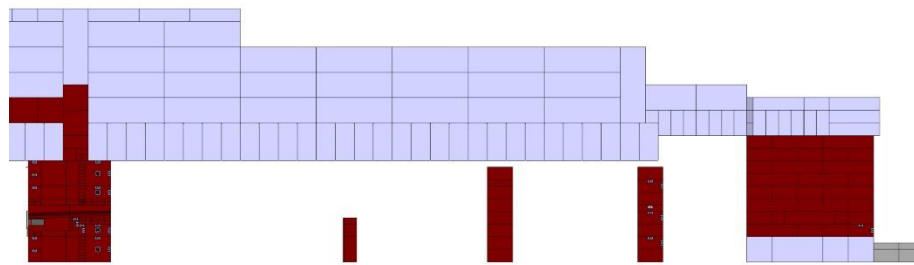


Fig. 4-54: Vertical cut of the roof shielding at the mixed zone.

4.10.7 T09-10 zone

For the T09 zone, the T09 experimental zone beam dump was designed taking into account a pion beam of 15 GeV/c with a maximum 5×10^6 pions per spill. The shielding in Fig. 4-55 shows that the T09 control room is not in direct continuation of the T09 beamline, in order to avoid the direct muons coming from the beam traversing the shielding.

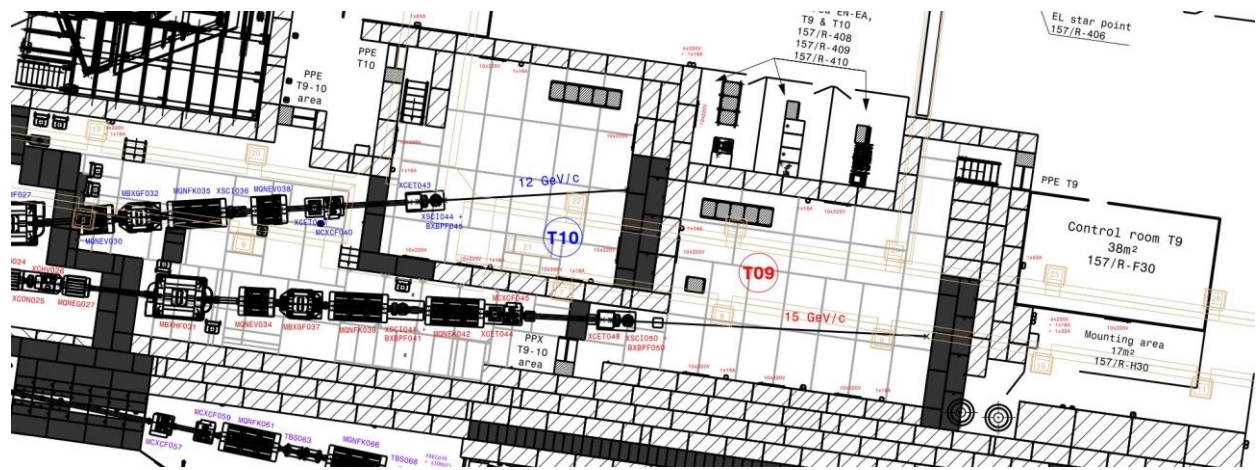


Fig. 4-55: T09-10 experimental zone.

4.11 Radiation monitoring

4.11.1 Purpose of the radiation monitoring system

The purpose of the radiation monitoring system is threefold. First, it has to provide radiological area surveillance to ensure that the ambient dose equivalent rates at locations accessible during beam operation remain below the limits determined by the radiological area classification. Second, the radiation levels due to residual radiation are measured prior to granting access to the primary zone to ensure that the radiation levels are optimized and that they are consistent with the ones used for the work and dose planning. Third, the airborne radioactivity that is released by the ventilation system to ensure the dynamic confinement of the primary zone is monitored.

4.11.2 Radiation fields in the East Area

The following radiation fields have to be monitored in the East Hall:

- i) Neutron stray radiation emerging from beam interaction after traversing the shielding structures.
- ii) Muons traversing the shielding structures: the only radiological relevant location in the East Hall is downstream of the CHARM beam dump where a dedicated radiation monitor is already installed. The muon fluxes downstream of the T09, T10, and T11 areas are very low; a fact that will be confirmed by dedicated measurements using mobile devices during the commissioning phase after LS2.
- iii) Photons from the decay of residual radioactivity in the primary zone.

4.11.3 Radiation monitoring devices

A general description of the CERN radiation monitoring system is given in Ref. [60]. High-pressure hydrogen ionization chambers (20 bar), designated as IG5-H20 AMF, will be used to measure neutrons. Air filled ionization chambers, designated IAM, will be used to measure photons from residual radiation in the primary zone. A ventilation gas monitor, designated as VGM, will monitor the airborne radioactivity released by the ventilation system for the primary zone that guarantees dynamic confinement.

4.11.4 Layout of the future radiation monitoring system

The preliminary layout of the radiation monitoring system related to the East Area Renovation project is shown in Fig. 4-56. The currently installed monitor chambers will be re-used. Therefore, the identifiers of the monitors

to be relocated are also given in Fig. 4-56. This means that only two new, high-pressure hydrogen ionization chambers (indicated as AMF) and one new VGM will need to be installed for the East Area Renovation project.

The layout of the already installed radiation monitoring system related to the IRRAD and CHARM facilities can be found in Ref. [61]. These monitors will remain at their present locations, except PAXEA811N and PAXEA821N. These two monitors will be re-located and their future position is indicated in Fig. 4-56.

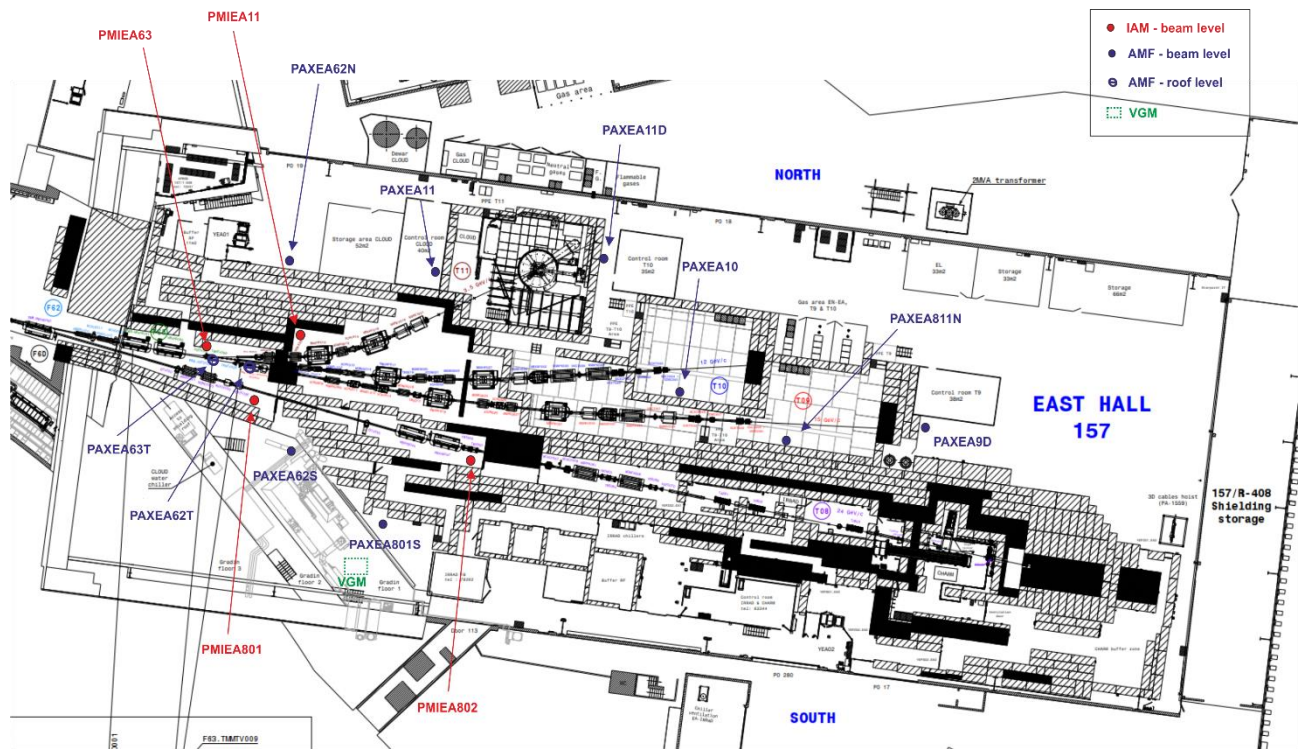


Fig. 4-56: Location and types of radiation monitors (IAM - induced activity monitor, AMF - area mixed field radiation monitor, VGM - ventilation gas monitor) related to the East Area Renovation project. The radiation monitors for IRRAD and CHARM are not indicated [61], except for PAXEA811N and PAXEA821N, that will be relocated.

References

- [1] MCB magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/188/>.
- [2] M100 L magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1903/>.
- [3] M200 L magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1904/>.
- [4] Specification of the bending magnets for the ISR beam transfer system, ISR/BT group (I-5010-ISR) (CERN, Geneva, November 1967) [EDMS 1100428](https://cds.cern.ch/record/1100428).
- [5] M100 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/154/>.
- [6] M200 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/160/>.
- [7] QDS magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/325/>.
- [8] QFS magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/336/>.
- [9] QFL magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/335/>.
- [10] Q100 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/334/>.
- [11] Q200 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/350/>.
- [12] Q100 L magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1902/>.
- [13] Q200 L magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1921/>.
- [14] Q74 L magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1281/>.

- [15] Q120 C magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1901/>.
- [16] Q74 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/311/>.
- [17] Q120 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/338/>.
- [18] MEA19 magnet, NORMA database, <https://norma-db.web.cern.ch/magnet/idcard/1343/>.
- [19] MDX magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/231/>.
- [20] CR200 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1906/>.
- [21] Study of the magnetic coupling between the CR200 and the Q120 C in the new East Area layout, [EDMS 2002996](#) (2018)
- [22] MDX L 150 magnet, NORMA database, <https://norma-db.web.cern.ch/magdesign/idcard/1905/>.
- [23] J. Burnet, and K. Papastergiou, Energy Saving; an example of a test facility upgrade with pulsed magnets instead of DC magnets, saving 90% of energy consumption, [EDMS 1770483](#) (2013).
- [24] J. Cottet, and J. Burnet, East Area energy balance and possible improvements, [EDMS 1255278](#) (2012).
- [25] S. Evrard, East area renovation: notes BE-OP meeting, [EDMS 1886001](#) (2017).
- [26] K. Papastergiou, Minutes of meeting with Rende Steerenberg and Lau Gatignon, [EDMS 1506818](#) (2015).
- [27] I. Josifovic, and L. Sbrulino, Accelerated aging tests of electrolytic capacitors, [EDMS 1804172](#).
- [28] L. Sbrulino, Lifetime investigation of electrolytic capacitors in power cycling applications, [EDMS 1597459](#) (2016).
- [29] E. Coulinge, and K. Papastergiou, Thermal stress and lifetime of power semiconductors in PS transfer lines, [EDMS 1458404](#) (2012).
- [30] S. Maestri *et al.*, Study of power converter topologies with energy recovery and grid power flow control Part B: boost converter with energy storage, CERN-ACC-2015-0049, <https://cds.cern.ch/record/2016791>.
- [31] S. Maestri *et al.*, Study of power converter topologies with energy recovery and grid power flow control Part C: a review of alternative structures, CERN-ACC-2017-0089, <https://cds.cern.ch/record/2291044>.
- [32] S. Maestri *et al.*, Study of power converter topologies with energy recovery and grid power flow control. Part A: 2-quadrant converter with energy storage, CERN-ACC-2015-0026, <https://cds.cern.ch/record/1994175>.
- [33] K. Papastergiou, and A. Harle, Electrolytic capacitors failure mechanism, [EDMS Folder-0000189820](#) (2018).
- [34] Papastergiou, K., Post-LS2 EIS-chain management specification for power converters, [EDMS 2045163](#) (2018).
- [35] K. Papastergiou, Functional specification: Economy mode operation in accelerator transfer lines, [EDMS 1493325](#) (2015).
- [36] E. Harrouch, and V. De Jesus, Vacuum control system for the East Area, CERN, [EDMS 1737544](#) (2016).
- [37] A. Pilan Zanoni, Description and thermo-mechanical analysis of the beam stoppers BI.STPFA and BI.STPS, [EDMS 1698144](#) (2016).
- [38] A. Pilan Zanoni, Thermo-mechanical analysis of the beam stopper BTY.STP103, [EDMS 1703654](#).
- [39] A. Pilan Zanoni, Description and thermo-mechanical analysis of the beam stopper BTP.STP10, [EDMS 1742948](#) (2017).
- [40] A. Pilan Zanoni, Description and thermo-mechanical analysis of the beam stoppers in the PS extraction (F16, FTA and FTN) lines, [EDMS 1691345](#) (2017).
- [41] A. Pilan Zanoni, PS beam stoppers, [EDMS 1871447](#) (2018).
- [42] A. Pilan Zanoni, Engineering and design of the new PS beam stoppers, [EDMS 1979131](#) (2018).

- [43] A. Pilan Zanoni, Core of the PS beam stoppers, [EDMS 1899978](#) (2018).
- [44] V. Agoritsas, Secondary emission chambers for monitoring the CPS ejected beams, Daresbury Symposium on Beam Intensity Measurement, 23–26 April 1968, <https://cds.cern.ch/record/299104>.
- [45] I. Ortega *et al.*, *Jour. Phys.: Conf. Ser.* **763** (2016) 012012, <https://doi.org/10.1088/1742-6596/763/1/012012>.
- [46] E. Harrouch, and M. Lazzaroni, Beam instrumentation needs for the East Area renovation, [EDMS 1865542](#) (2018).
- [47] D. Missiaen *et al.*, Definition of the MADx output file for survey, [EDMS 2052453](#) (2019).
- [48] M. Zerlauth, and R. Mompo, Warm magnet interlock controller software functionality, [EDMS 1360775](#) (2016).
- [49] A. Miranda Fontan, and R. Mompo, WIC magnet interlock system for the East Area, [EDMS 2037701](#) (2018).
- [50] S. Deghaye, BE-CO plans for LS2, [EDMS 1997812](#) (2018).
- [51] S. Evrard, North Area Collimators, [EDMS 1505414](#) (2015).
- [52] J. Meignan, Engineering Spec. for the new TCX in the primary Area, [EDMS 1889861](#) (2017).
- [53] L. Gentili, TCS collimator plug-in ball support, [EDMS 624352](#) (2016).
- [54] M. Lazzaroni, J. Bernhard, and E. Harrouch, Beam stopper, stopper dump and target, [EDMS 1786687](#) (2018).
- [55] D. Forkel-Wirth, Zonage radiologique au CERN, [EDMS 810149](#) (2017).
- [56] T.T. Böhlen *et al.*, *Nuclear Data Sheets* **120** (2014) 211–214, <https://doi.org/10.1016/j.nds.2014.07.049>.
- [57] A. Ferrari *et al.*, FLUKA: a multi-particle transport code, CERN (2005), CERN-2005-10, INFN/TC_05/11, SLAC-R-773, <http://dx.doi.org/10.5170/CERN-2005-010>.
- [58] E. Iliopoulou, and R. Froeschl, Radiation Protection assessment of the shielding design of the East Area target zone and test beamlines, [EDMS 2058239](#) (2018).
- [59] E. Iliopoulou, and R. Froeschl, Status update on the RP assessment for the East Area Renovation Project, [EDMS 1974733](#) (2018).
- [60] D. Perrin, Description of the CERN radiation and environmental monitoring system, CERN-RP-2017-027-REPORTS-TN, [EDMS 1723230](#) (2017).
- [61] R. Froeschl, Radiation protection assessment of the proton irradiation and the CHARM facility in the East Area, CERN-RP-2014-008-REPORTS-TN, [EDMS 1355933](#) (2014).

Chapter 5 Infrastructure consolidation

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5.1 Civil engineering

5.1.1 Introduction

Constructed in 1963, Building 157 is 113 m long and 43 m wide at ground level. The roof is 21.8 m high at the central point above a skylight running longitudinally down its centre; it has a slope of 20% running down to the longitudinal façade summits at 15.6 m. The roof is 47.4 m wide as the longitudinal façades include wings protruding 2.2 m from a height of 7.5 m to the summits, running the entire length of the building. The longitudinal façades are made up of a variety of materials (masonry, wood agglomerate, fibro-cement, and glass, see Fig. 5-1 numbering for a detailed explanation). The end walls are made of reinforced concrete (Northwest wall) or wood agglomerate (Southeast wall).

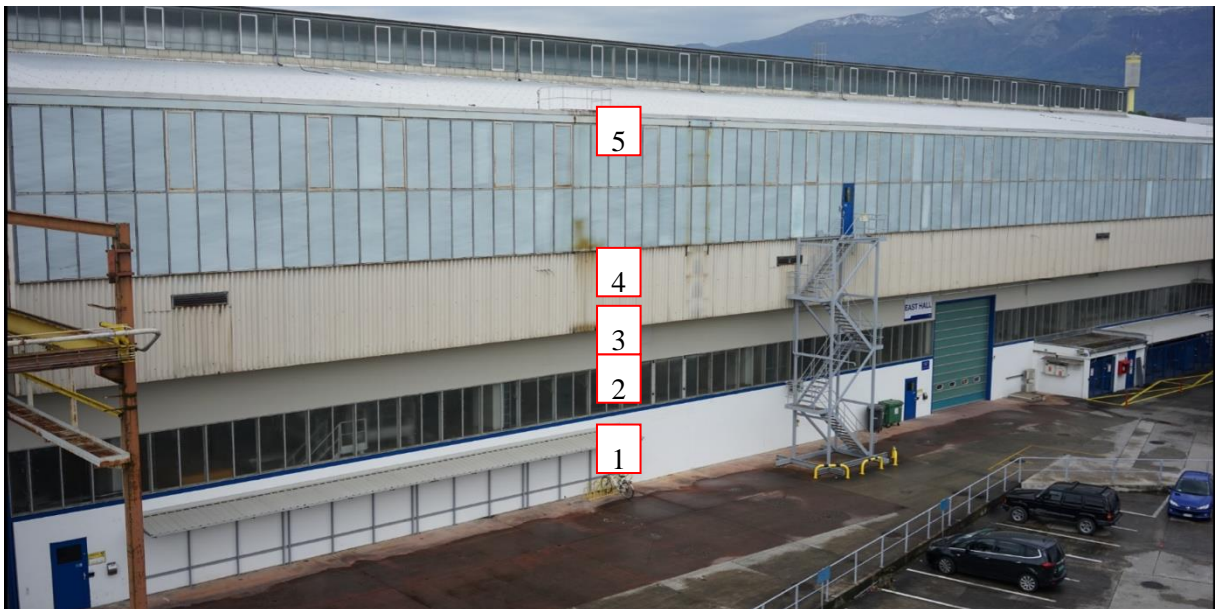


Fig. 5-1: East Hall as seen from the SMB-SE drone with material identification.

1. Masonry walls.
2. Lower windows (Northeast façade only).
3. Wood agglomerate panels (Durisol).
4. Corrugated fibro panels (forming the base and the lower part of the wing).
5. Two levels of mid-level windows.

The East Hall is now 55 years old and many facets of the building envelope are in an unacceptable state. There are dilapidated and unsafe materials forming and falling from the envelope of the building. The uninsulated envelope does not conform to current building energy-management requirements, resulting in disproportional thermal losses and hence financial losses due to heating requirements.

The envelope renovation project has two principal objectives with a number of specific objectives [1].

- ‘To improve the safety and comfort in the building by replacing the existing envelope’.

- Removing the dilapidate asbestos-containing ceiling panels.
 - Removing existing poorly fixed, single-glazed windows with asbestos containing joints.
 - Removing existing uninsulated fibro-cement façade panels.
 - Eradicating the water infiltrations coming from the roof.
- To ensure a synergy with the consolidation of the façade of the attached Building 156 (see Fig. 5-2).

As such, the entire envelope was studied in an attempt to create a safe environment, optimizing energy savings, responding to modern building codes, and respect an aesthetic liaison with Building 156.



Fig. 5-2: Sky view of Buildings 157 and 156.

5.1.2 Solutions

5.1.2.1 Long façades

All surfaces of the long façades will be modified to improve the safety, insulation (see Table 5-1), and functionality of the building, as well as the aesthetics (see Fig. 5-3) [2].

- i) The masonry walls will be insulated via the exterior face with sandwich panels.
- ii) The lower windows will be replaced with better-insulated windows.
- iii) The Durisol panels will be insulated via the exterior face with sandwich panels.
- iv) The Eternit panels will be removed and replaced with 120 mm sandwich panels.
- v) The lower part of the mid-level windows will be replaced with 120 mm sandwich panels. The upper part of these windows will be replaced with translucent polycarbonate panels equipped with heat-stop film on the exterior face. This will allow the passage of non-direct sunlight whilst reducing the impact of extreme heat during the summer time and eliminating direct sunlight from the building.

Table 5-1: Comparison between existing and new materials thermal transmittance values for long façades.

Existing material	Existing U [W/m ² K]	New material	New U [W/m ² K]
Masonry walls	2	Masonry walls + 100 mm sandwich panels	0.17
Lower windows	5	New lower windows	1
Durisol panels	1	Durisol panels + 100 mm sandwich panels	0.16
Eternit	3	120 mm sandwich panels	0.19
Mid-level windows	5	120 mm sandwich panels/polycarbonate panels	0.19/1.1

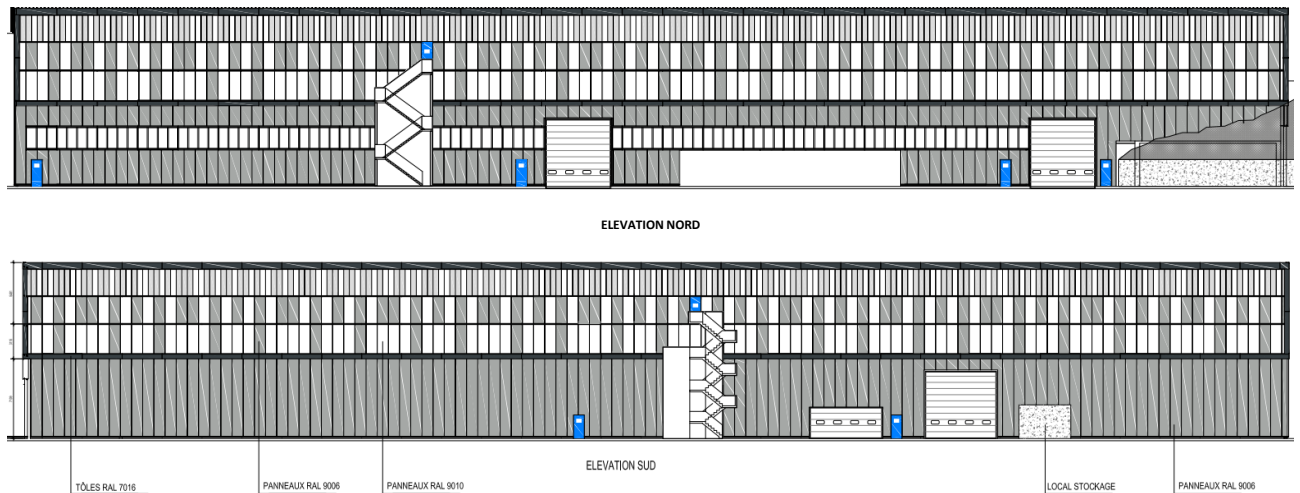


Fig. 5-3: Future Northeast and Southwest façade materials.

5.1.2.2 Roof and ceiling

Many solutions were considered for the replacement of the ceiling/roof system, however, the optimal solution chosen is the removal of the asbestos containing ceiling panels and insulation and the dismantling of the roof sheet. These will be replaced by a single system of insulated sandwich panels placed above the roof structure. Furthermore, the existing sky lantern will be demolished and replaced with a classic gable roof (see Fig. 5-4), as is already the case for the two extremities of the building. This demolition allows for a reduction of a lost heating volume at the top of the building, it also reduces a number of thermal bridges given the number of different materials constituting the sky lantern.

Due to the removal of the current building smoke ventilation opening windows, classic ventilation traps will be added to the roof as illustrated in Fig. 5-5. This allows the upgrade to the correct extraction surface to improve the safety of the building.

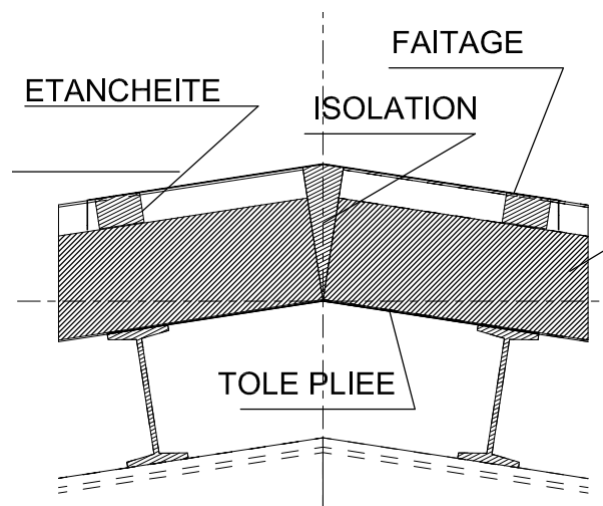


Fig. 5-4: New gable roof peak design.

COUPE AVEC SKYDOME

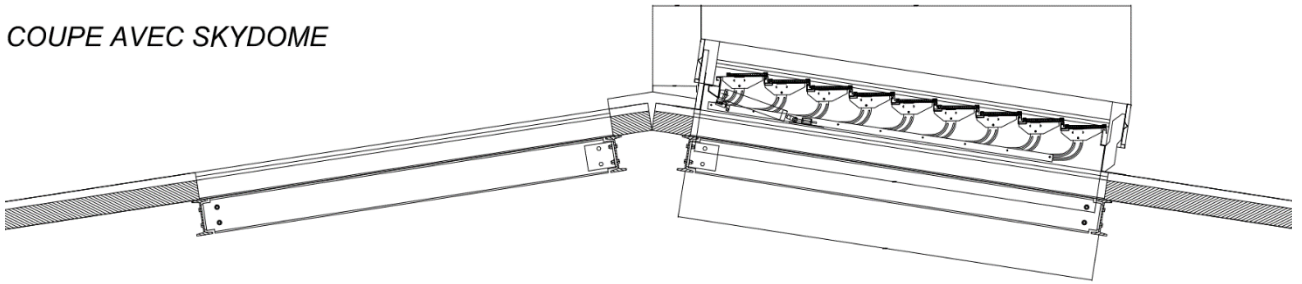


Fig. 5-5: New smoke ventilation trap.

5.1.2.3 End walls

The Northwest end wall will be insulated using 100 mm sandwich panels on the exterior face of the existing concrete (Fig. 5-6). This will only be carried out on the area of the wall that is above the fill level of the PS as the underground portion of the façade is not susceptible to significant heat losses.

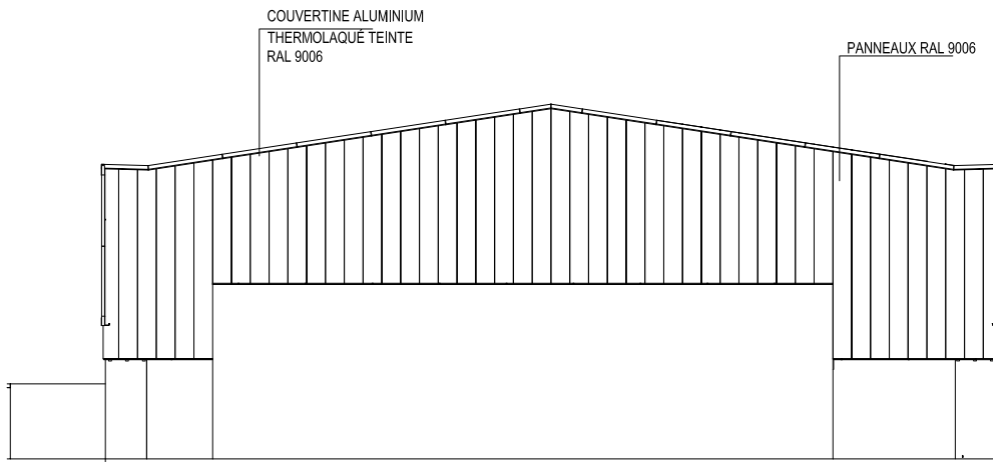


Fig. 5-6: Northwest end wall.

The Southeast wall is made of wood agglomerate (Durisol) panels and is insulated using 100 mm sandwich panels uniquely where it is exposed to the exterior. The large rectangular opening visible in Fig. 5-7 represents the portion of the wall giving to the Building 156 hangar.

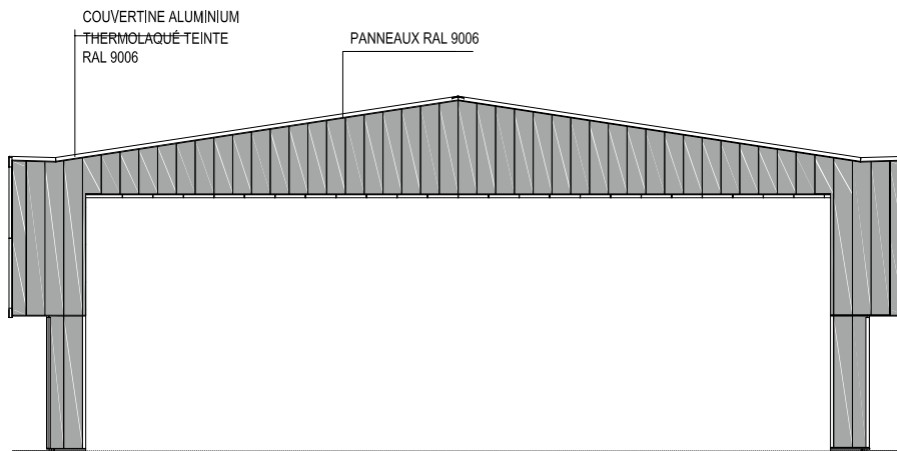


Fig. 5-7: Southeast end wall.

5.1.3 Conclusions

The new envelope provides a significant reduction in building energy losses. The simplified calculation shows that there is an 89% reduction in energy losses through the building envelope.

This new envelope equally provides a much safer and more functional work environment whilst at the same time making a drastic aesthetic improvement to the building (see Fig. 5-8).



Fig. 5-8: Architects 3D rendering of future upper Northeast façade.

5.2 Cooling plant and circuits

5.2.1 Scope

The scope of this project is to consolidate the demineralized water-cooling systems for the East Area magnets and power converters as follows (Fig. 5-9 summarizes the solution):

- i) provide demineralized water cooling to magnets in Building 157 mixed and secondary zones;
- ii) provide demineralized water cooling to equipment test lines employed by CERN High Energy AcceleRator Mixed field facility/proton IRRADiation facility (CHARM/IRRAD) users in Building 157;
- iii) provide demineralized water cooling to power converters in Building 355 hall;
- iv) provide demineralized water cooling to power converters in Building 251;
- v) provide a dedicated demineralized-water cooling circuit to magnets inside Building 157 primary zone bunkers, PS, and to those CHARM/IRRAD equipment test lines that are installed inside CHARM bunker.

5.2.2 User's requirements

The requirements for magnets, CHARM/IRRAD equipment test lines, and power converters are summarized in Table 5-2 and in Ref. [3].

No specific requirements are made for pH and O₂ values. The demineralized water circuits shall have sampling points for water analysis purposes.

The demineralized water-cooling system shall have an n+1 redundancy on pumps. No connection to the secured network is required.

Table 5-2: East Area demineralized water: user requirements.

Cooling requirements	Unit	Magnets circuit – mixed and secondary zones	Magnets circuit – primary zones + PS	B355 Power converters circuits	B251 Power converters circuits	CHARM/IRRAD Equipment lines (External)	CHARM/IRRAD Equipment lines (R-050)
Nominal supply temperature	[°C]	27	30	27	27	27	30
Maximum supply temperature	[°C]	28	31	28	28	28	31
Maximum cooling power of the system – cycling operation	[kW]	142	150	120	398	14	7
Maximum flow rate	[l/min]	961	561	467	1 764	20	10
	[m ³ /h]	58	34	28	106	1.2	0.6
Pressure rating		PN25	PN25	PN16	PN16	PN10	PN10
Water conductivity	[µS/cm]	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

5.2.3 Technical solution

The cooling of magnets, CHARM/IRRAD equipment test lines, and power converters is overseen by 2 cooling stations and the associated distribution networks as follows (see Ref. [4]).

- **Demineralized water station – Building 355 – FDED-00355** - that will supply demineralized water to magnets in Building 157 mixed and secondary areas, CHARM/IRRAD equipment test lines in Building 157 hall and power converter in Building 251 main hall. It will also act as primary for the demineralized water skid FDED-00251 (Building 157).
- **Demineralized water skid – Building 157 – FDED-00251** - that will supply demineralized water to the magnets in Building 157 primary zone bunkers and Building 352 and to the CHARM/IRRAD equipment test line installed in CHARM bunker 157/R-050.

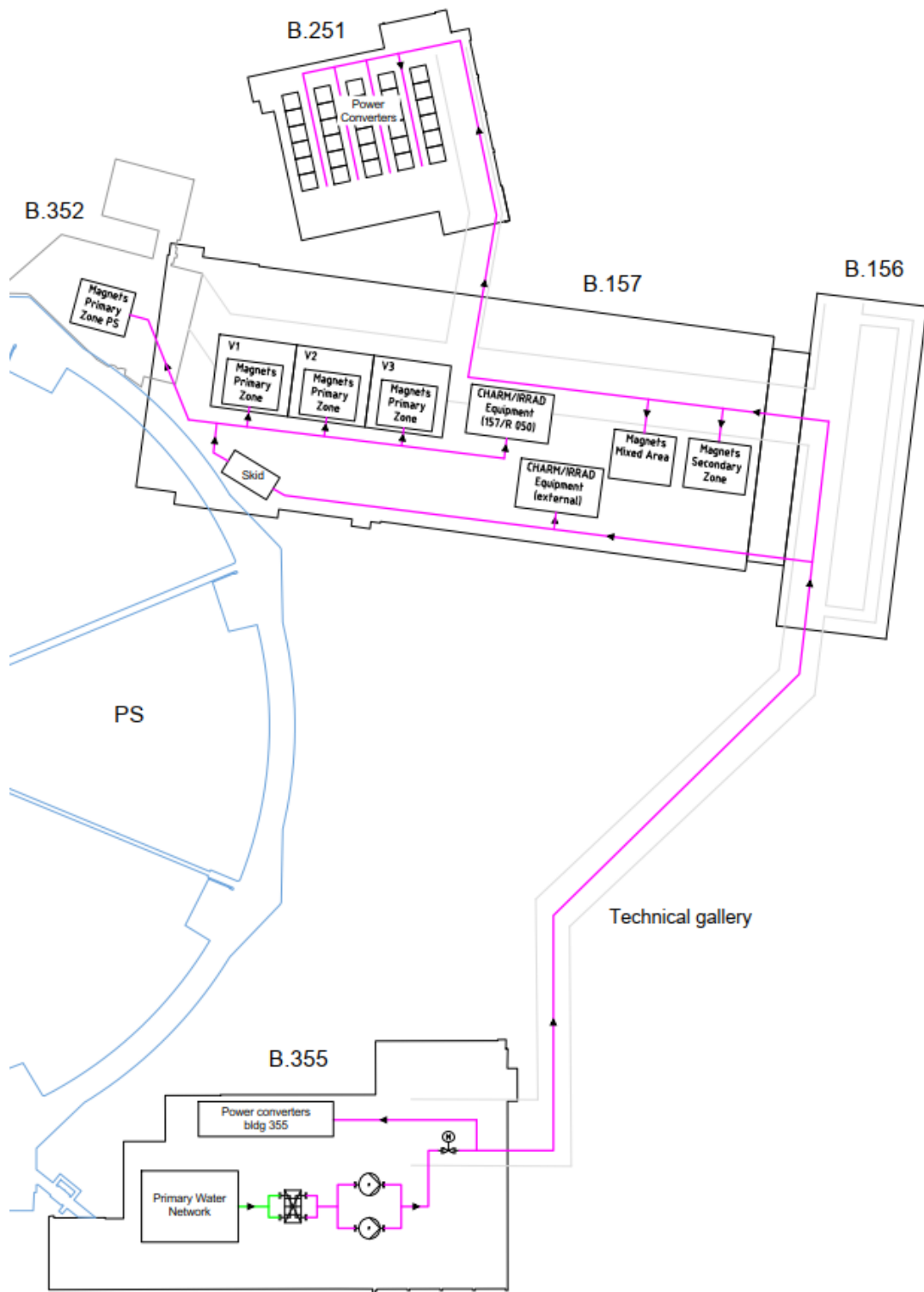


Fig. 5-9: Synoptic of the East Area demineralized water distribution.

5.2.3.1 Demineralized water distribution network

Figure 5-9 shows the synoptic of the demineralized water distribution network. All existing piping of correct nominal diameter (ND) size and in good status will be preserved and reused, the remaining will be replaced. Redundant pipework will be removed.

Pipework will be routed in technical galleries and then supply demineralized water to:

- **magnets:** pipework will be installed along the various beamlines arriving in close proximity to each magnet in order to minimize pressure drops in flexible piping. Pressure reducing valves will be installed on main branches after having supplied demineralized water to those magnets with the highest pressure drop;
- **power converters:** the piping coming from the cooling station will split in one DN100 and one DN125 branches that will branch off piping of sizes ranging from DN40 to DN50 to reach each cluster of power converters. Pressure reducing valves will be installed on the main branches;
- **CHARM/IRRAD equipment test lines:** the existing distribution to CHARM/IRRAD equipment test lines external to the shielding block will be kept. The current test lines have pressure reducing valves from 25 to 12 bar; as the new demineralized station, Building 355 will supply demineralized water with a pressure of up to 14 bar; new pressure reducing valves will replace the existing ones. The final distribution to CHARM/IRRAD equipment test line inside CHARM bunker will branch off the pipework supplying demineralized water to the magnets in the V3 bunker.

5.3 Buildings 157 and 251 ventilation

5.3.1 Building 157 ventilation

5.3.1.1 Scope

The scope of this project is to consolidate the heating, ventilation, and air conditioning (HVAC) system of Building 157 hall to provide heating during winter and ventilation during summer.

5.3.1.2 User requirements

The ventilation requirements for the Building 157 hall are listed in Table 5-3 and in Ref. [5]. No humidity regulation is needed. All fresh and recirculated air will be filtered. Redundancy of any functionality of the HVAC systems is not required during normal operation or in the case of a power cut or fault in the electrical power supply systems.

Table 5-3: Building 157 hall: ventilation requirements

Temperature range [°C]	Min fresh air rate per person [m ³ /h]	Max occupancy [persons]
17–29	45	100

5.3.1.3 Technical solution

The HVAC system of B157, which is illustrated in Fig. 5-10, will have:

- i) **Eight air-handling units (AHUs)** – four on the North side with a nominal flow rate of 12 000 m³/h and four on the South side with a nominal flow rate of 9 000 m³/h. Each unit will be equipped with heating coils for winter temperature control and summer ventilation. They will have fresh air intake that will provide minimum 1 000 m³/h each.
- ii) **Eighteen destratification fans** – with a nominal flow rate of 9 000 m³/h and 5 300 m³/h installed on roof supporting steelwork. These fans will help de-stratify the temperature gradient associated with convective heating.

- iii) **Two air curtains** – to prevent a cold draft from entering the building during operation of the two stacking doors on North façade.
- iv) **Hot water station and distribution circuits** to feed the heating coils of the AHUs.

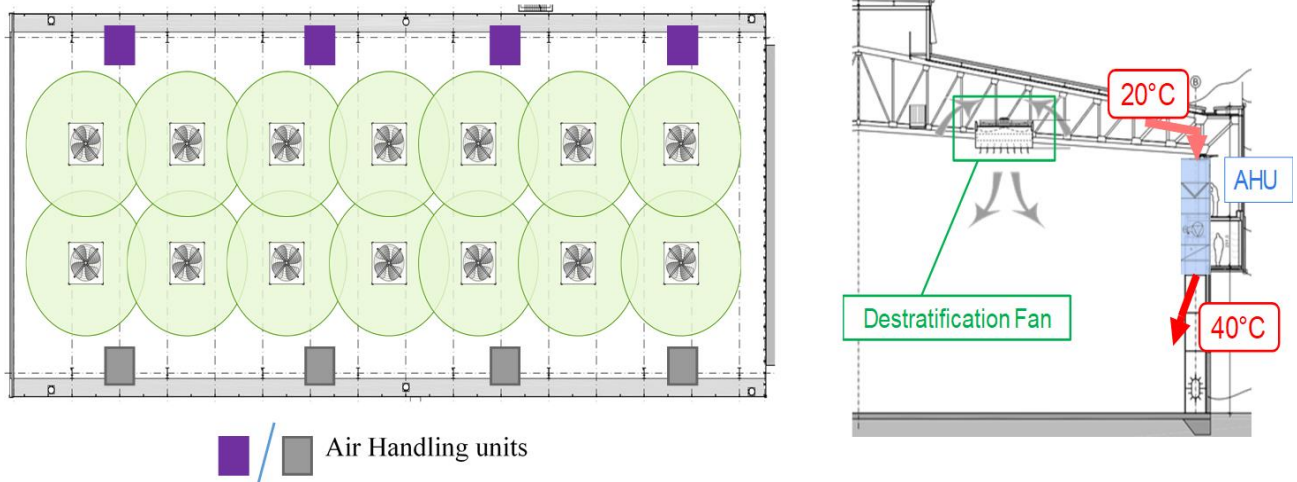


Fig. 5-10: Left: top view of Building 157 with the position ventilation systems, right: vertical cut of Building 157.

The air handling units will have a common mixing chamber where fresh air is mixed with recirculated air. This will normally occur in summer when the units will work with full fresh air during nights and with recirculation during hot periods of the day.

Air will be supplied by new ductwork installed along the building walls. The ducts will have a single wall construction and have grilles to ensure uniform distribution in the building. The return air intake will be on top of each air handling unit.

5.3.1.4 Safety aspects

In case of fire detection and power failure, all AHUs and destratification fans will automatically stop and all dampers will close.

5.3.2 Building 251 ventilation

5.3.2.1 Scope

The scope of this project is to provide HVAC systems to the following.

- **Power converter hall (R-007)** – to ensure temperatures inside power converters are within their operating limits and to prevent frost damage in pipework installed in false floor.
- **Plant room (R-005)** – to provide heating during winter periods to avoid frost damage.

5.3.2.2 User's requirements

The air-cooling requirements for power converters are as listed in Table 5-4 and in Ref. [5]. The minimum temperature inside power converters is 15°C and maximum temperature is 33°C immediately above the capacitors and of 38°C above the capacitors. No condensation will occur.

Ventilation air will be filtered. Redundancy of any functionality of the HVAC system for power converters is not required during standard operation as well as maintaining specific functionalities in degraded mode or in case of power cut or fault in the electrical power supply systems.

Table 5-4: Building 251 power converters: air cooling requirements.

Power converter type	Number of installed power converters	Dissipated unit power via air cooling [kW]	Total dissipated power via air cooling [kW]
SIRIUS S	19	1.4	26.6
SIRIUS 2P	25 + 1 (spare)	2.6	65.0
SIRIUS 4P	9	4.9	44.1
SIRIUS 4P+	8 + 2 (spare)	5.9	47.2
TOTAL			182.9 kW

5.3.2.3 Technical solution

The HVAC system of Building 251 will have the following.

- **Two air handling units** – with a nominal flow rate of 31 000 m³/h each and heating and cooling coils for temperature control and frost prevention of power converters hall 251/R-007.
- **Two heating units** – with a nominal flow rate of 10 000 m³/h with heating to coil to provide heating to plant room 251/R-005.
- **Chilled water and superheated water distribution circuits** to feed the air handling and heating units.

The air handling units will have a common mixing chamber where fresh air is mixed with recirculated air. This will normally occur in winter and in summer, when the recirculated air is cooler than external air. In summer, when recirculated air is hotter than the external air, the units will work with full fresh air. Air will be blown by two air handling units into the plenum between the building floor and false floor and it will flow through the power converters before being either recirculated or exhausted, as illustrated in Fig. 5-11. Motorized dampers installed at a high level in the power converter hall will serve as air exhausts.

Air ducts will be of double wall construction for air supply above the false floor and single wall construction inside the false floor. Air ducts will have grilles to ensure uniform distribution amongst power converters. Heating units will ensure minimum temperatures are maintained in the plant room and that there will be no frost.

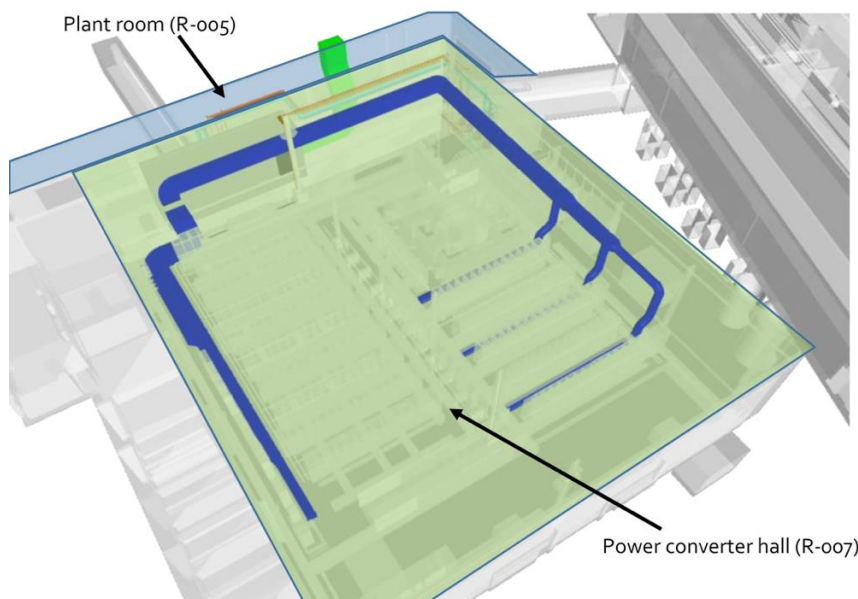


Fig. 5-11: View of the Building 251 and the position of the ducts (in blue) in the power converter hall.

5.3.3 Safety aspects

In case of fire detection and power failure, the HVAC system of Building 251 will automatically stop and all dampers will close.

5.4 Primary area ventilation

5.4.1 Scope of the project

The scope of this project is to provide HVAC systems to:

- **Primary zone bunkers** – to contribute to ensuring a dynamic confinement of the bunkers (Fig. 5-12) during operation, to provide the flush of the bunkers before access, to cope with the heat load of the magnets, and to guarantee the required temperature stability.
- **Mixed area** – ensuring fresh air supply during access to the area.



Fig. 5-12: Location of the primary zone bunkers (V1, V2, and V3) and the mixed area.

5.4.2 User's requirements

The HVAC systems shall operate in three modes (see Refs. [6] and [7]).

- Beam mode – when beamlines and magnets can receive the beam.
- Flush mode – when beamlines and magnets will not be receiving the beam and activated air is flushed out of the primary zone bunkers; no flush is required for mixed area.
- Access mode – when access to primary zone bunkers is possible.

The HVAC system of the primary zone bunkers will ensure that temperatures are kept to $22 \pm 3^\circ\text{C}$ inside the bunkers in all modes of operation. Recirculated air and exhausted air will be filtered with F9 filters. No humidity control is required.

This HVAC system will ensure dynamic confinement of the primary zone bunkers during the beam and flush mode so that the bunkers are in underpressure with respect to adjacent areas (with an air permeability rate of $10 \text{ m}^3 \text{ h}^{-1} \text{ m}^{-2}$ at 50 Pa the pressure difference should be -20 Pa). An interlock between the HVAC system of the primary zone and the access system (see Section 5.8) is required to prevent access during beam and flush modes.

The HVAC system of the mixed area will ensure the minimum supply of fresh air to the mixed area premises for safety reasons. No interlock with the access system is required. Redundancy of the ventilation system and connection to the secured network are not required.

5.4.3 Technical solution

The HVAC system of the primary zone bunkers will have (Fig. 5-13):

- i) **One air handling unit – UARJ-00043** – with a nominal flow rate of 5 400 m³/h.
- ii) **One extraction unit – UAEJ-00037** – with a nominal flow rate of 10 200 m³/h.
- iii) **Airtight filter casing – UAEF-00017 and UAEF-00018** – with F9/ePM1 80% filters that will filter the recirculated and exhausted air, respectively.
- iv) **Air cooled chiller – FCK-00182** – with chilled water production range 12–18°C.

Air ductwork will be of double wall construction for air supply and single wall construction for air return, fresh air, and exhaust air. Routes, diameters, and additional information can be found in Ref. [7].

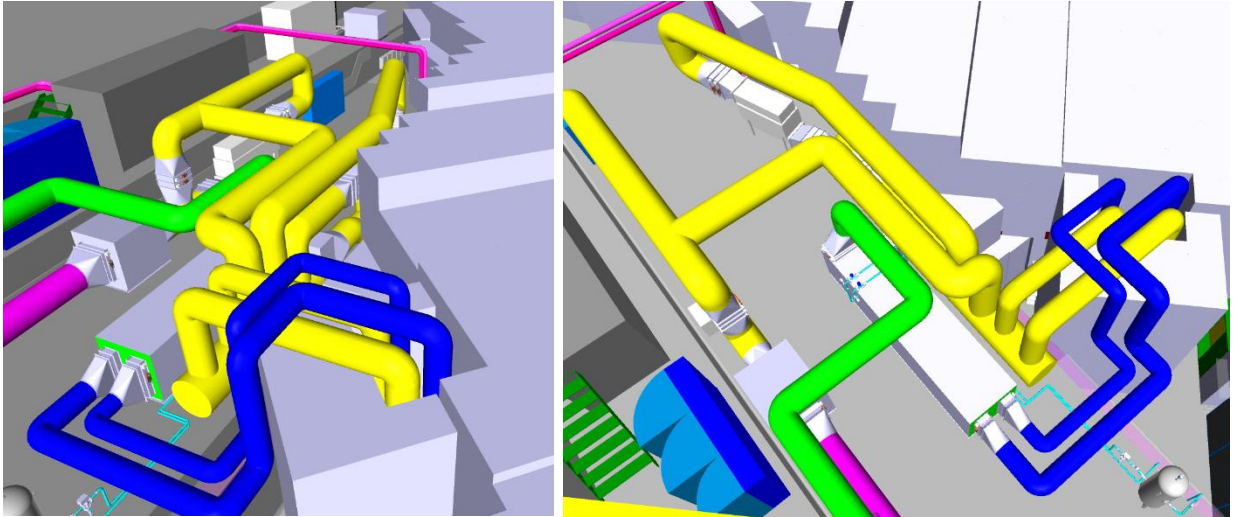


Fig. 5-13: Three-dimensional integration of the air handling units and the ducts for the primary area.

The ventilation system of the mixed area will have a supply fan that will supply air from the hall to the mixed area bunker during flush and access modes. It will be off during beam mode.

In case of fire detection, the ventilation systems for the primary zone and mixed area bunkers will automatically stop and all dampers will close as the beam and the heat loads will be switched off.

In case of power failure, the ventilation system for the primary zone and mixed area bunkers will stop.

To cope with radioprotection requirements, the air ducts will be routed through a chicane made of concrete blocks, as shown in Fig. 5-13.

5.5 Electrical distribution

5.5.1 Introduction

This section describes the consolidation of the electrical infrastructure [5] in the East Hall (Building 157) and in electrical substations ME11 (Building 251), ME8 (Building 252), and ME22 (Building 263).

In the existing network, seven 18/0.4 kV transformers supply the power converters and one supplies, from Building 252, the general services of Building 157 and other surrounding buildings. Two special transformers, which were already removed before the consolidation, supplied other converters.

The future design, based on the inputs received from the users, allows an important optimization of the installed power, with an improvement in terms of operation and maintenance.

5.5.2 Future network topology

Figure 5-14 illustrates the simplified future single line diagram: two transformers (EMT105*11 and EMT104*11) will supply the power converters in Building 251, one transformer (EMT103*11) the general services network of the area, and one transformer (EMT106*EH) the experimental areas in Building 157.

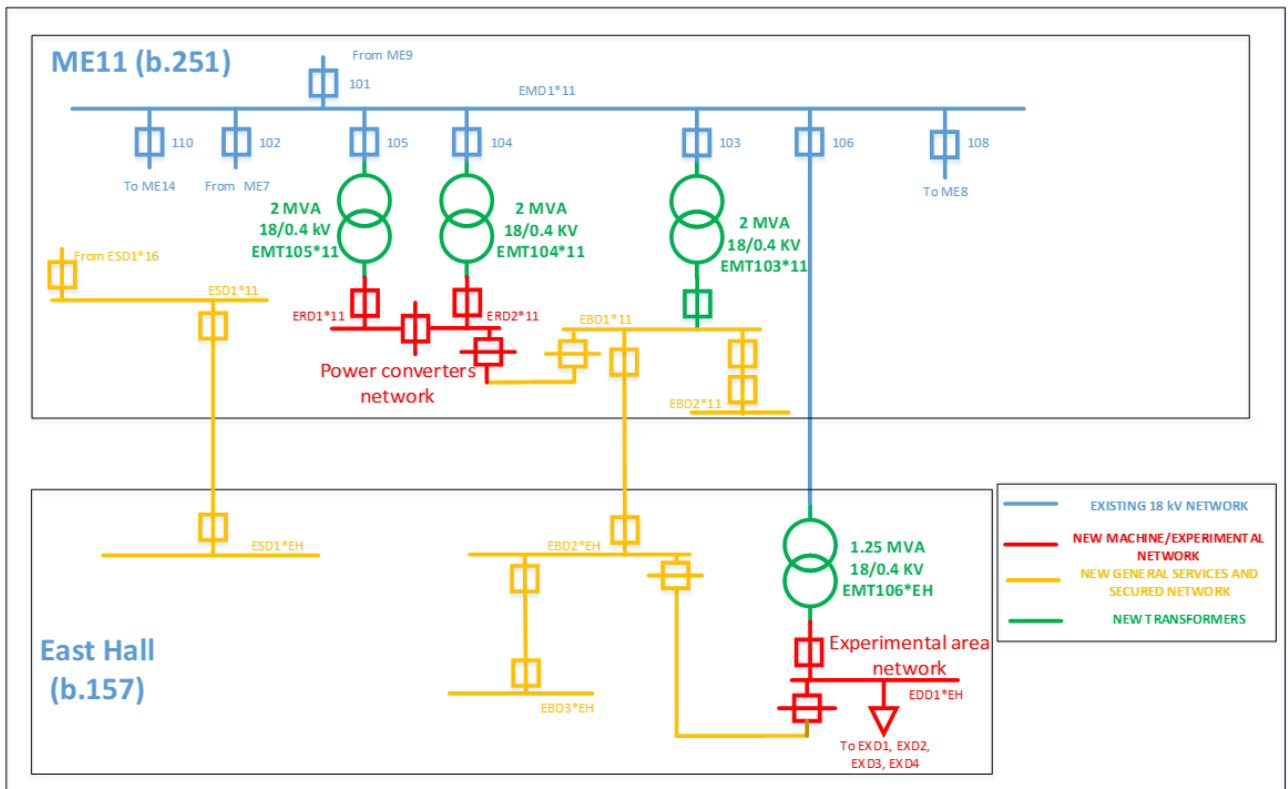


Fig. 5-14: Future single line diagram.

5.6 DC circuits

5.6.1 Existing wiring principle

The current wiring principle gives a lot of flexibility to the direct current (DC) circuits in the East Area. All the power converters are connected to a line selector in Building 251. This allows the operation team to choose to which terminal boxes (TBs) the DC power should be sent to (Fig. 5-15). Ultimately, the magnets can be connected to any of the terminal boxes in Building 157.



Fig. 5-15: Left: line selector in Building 251, right: terminal boxes in the technical gallery under Building 157.

5.6.2 Requirements

The advertised current intensities implemented by the converters are 200, 400, and 800 A [8]. For waste reduction reasons, it was determined if the existing cables could be re-used. The line selector (in light red in Fig. 5-16) and the TBs are in a very old state and shall be dismantled, meaning that the magnets will be directly connected to the power converters. DC circuits to Building 263 will be fully dismantled (in red in Fig. 5-16). Only the two extremities of the cables will be replaced (in yellow in Fig. 5-16).

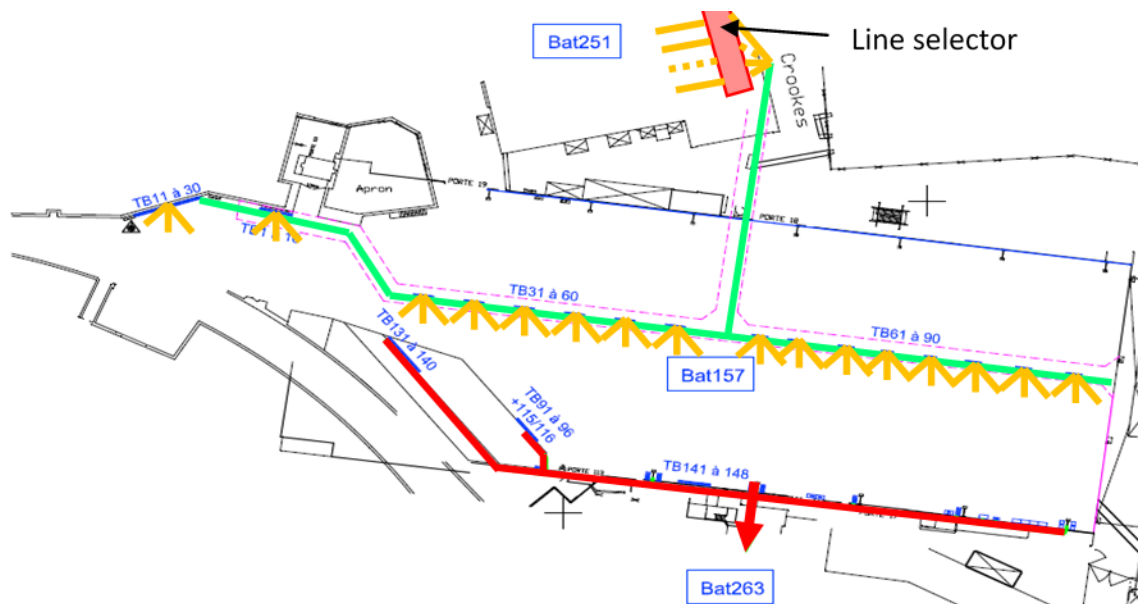


Fig. 5-16: DC cable wiring principle with the cables to be kept (green), replaced (yellow), and removed (red).

5.6.3 Technical solution

After study, the number of cables per circuit was determined as follows:

- 200 A: 1 × 240 mm² aluminium per polarity giving 0.125 Ω/km at 20°C.
- 400 A: 2 × 240 mm² aluminium per polarity giving 0.0625 Ω/km at 20°C.
- 800 A: 3 × 240 mm² aluminium per polarity giving 0.0416 Ω/km at 20°C.

The voltage drop induced by the existing cables is then compatible with the future power converters.

Table 5-5 shows the total quantity of cables and lengths (new cables amount to a total of 14 km) taken into consideration.

Table 5-5: Quantity of DC cables.

Beamline	Quantity of cables	Total Length (m)	Total length re-used (m)
F61	38	7 658	5 172
F62	14	2 852	1 792
F63	18	2 838	1 710
T08	42	5 412	3 186
T09	54	6 158	3 502
T10	48	5 770	3 198
T11	26	3 712	2 182
Total	240	34 400	20 742

5.6.4 Implementation

In the new layout, the distribution of magnets and converters is completely different, so it is not possible to keep existing cables at their current locations. The recoverable part is located between the entrance of Building 251 and the civil engineering openings of hall 157 and up to the TBs located in Building 352. At the interfaces, each $1 \times 240 \text{ mm}^2$ aluminium cable will be sleeved with a single-pole $1 \times 150 \text{ mm}^2$ copper cable [9].

5.7 Signal cables

Current beam control systems were implemented some twenty years ago. The technicality of some of them having evolved and the new configuration of the equipment of the beams being different, it was decided to:

- i) Remove signal cables from obsolete systems.
- ii) Remove signal cables from systems whose equipment is no longer in the same place.
- iii) Install new cables for new systems as well as those whose equipment has changed place.

5.7.1 Removal of signal cables

Careful identification has been performed [10] to quantify and identify the cables to be removed [11]: about 285 km of cables will be removed in four different buildings (157, 251, 352, and gallery 817).

5.7.2 Installation of new cables

All the cables to be pulled are summarized in Table 5-6.

Table 5-6: Details of new cables to be installed for East Hall Renovation project.

System	Quantity of cables
Machine Interlock	120
Beam instrumentation	150
Collimators control	18
Radiation monitoring	60
Targets control	36
Vacuum system	32
Beam stoppers	42
Access system	44
Gas detection	48
Controls for CHARM	27
Power converters control	67
Gas systems	37

5.7.3 Cable tray infrastructure

The cable trays installed in Building 251 and along the beamlines in the hall of Building 157 will be removed and replaced with new ones according to the new configuration of beamlines and concrete blocks. The removal corresponds to a total of 500 m.

Hall infrastructure paths as well as those existing in the gallery are retained and re-used.

5.8 Personnel protection systems

5.8.1 Introduction

This section describes the modifications required by the East Area Renovation Project to the existing personnel protection systems (PPS) regulating the access of personnel to the East Area primary and experimental zones. It presents the users' technical requirements and the system principles. The renovation includes the modification of two type of access systems:

- Access systems for primary beam areas:

Access to the East Area primary beamlines is managed by two independent areas, named EA1 and EA2, each managed by a PPS. Modification of the PPS of EA1 and PPS of EA2 IRRAD-CHARM concern the sectorization, the safety related elements, and the external safety conditions.

- Access system for secondary beam area and Building 157 control rooms, buffer zones, and storage rooms:

Access to each of the East Area experimental areas is managed by a PPE (personnel protection entry). The following modifications will be implemented:

- T09, T10, T11: PPEs re-located.
- New PPE for new zone T09-10.
- New function: EA experimental areas remote operation from the CERN CCC for veto management and chain tests.
- Access control on doors of control rooms, buffer zones, and storages located inside Building 157: re-located or new.

5.8.2 *PS complex PPS principles and role*

During Long Shutdown 1 (LS1), the PS Accelerator Complex access systems were renovated to cope with new operational needs and regulations and standards applicable for the ‘Installation Nucléaire de Base (INB)’.

Each zone is managed by a dedicated PPS and can be divided into different access sectors (equipped with various elements such as sector doors, end-of-zone doors, etc.). The access sectors are particularly important to organize the patrol of the machine and to minimize the radiation exposure by means of a radiation veto handled by the RP responsible person. Access to the zone is done via an *access point* composed of a personnel access device (PAD) and a material access device (MAD). Adjacent zones are separated through inter-machine doors. The closure of the external envelope of each zone is ensured by end-zone doors which are normally used only for evacuation in case of emergency.

The East Beam primary area is divided into two interlocked zones, EA1 for the primary beamline area and EA2 for IRRAD-CHARM primary areas.

The main role of the PPS is to ensure that there is no danger (radiological hazard or other risks identified in the APR [15][16] such as activated air) during personnel access to the zone, and that no personnel are present inside the zone during BEAM operation.

The PS PPS is composed of two complementary subsystems, the PS access control system (PACS) and the PS access safety system (PASS). The PACS ensures a physical barrier and controls access by means of automatic or remotely controlled security portals and access devices for personnel and material. Access points regulate personnel access to supervised and controlled machine areas, it ensures users identification, biometric authentication, and regulates at the highest safety level (single person check, audio, video, etc.) the access according to the operation modes managed remotely by the CCC.

The PASS ensures that at any time and in every operation mode of the various machines, the PS Complex is safe for the machine users by interlocking Access or Beam ‘Important Element for Safety (EIS)’ [14]. In Access mode, all the EIS beams are maintained in a safe state. In Beam mode, any intrusion within the PS Complex will immediately interlock the necessary EIS beam, stopping the beam operation to protect personnel from exposure to radiation hazards.

Each beam zone has its own independent access conditions. The absence of a beam in each independent beam zone is guaranteed by at least two beam safety elements, with at least one passive element (e.g. a moveable stopper) and one active element (e.g. magnetic power converter interlock).

The operation modes of the PS PPS are: Access, Ready for Access/ Ready for Beam (RFA/RFB), and Beam.

In ACCESS mode, safety vetoes are applied to all the EIS-beam/EIS-machine and EIS-external elements. Safety vetoes are removed from the EIS-access depending on the inter-locked zone safety conditions (radiation level, ventilation). In RFA/RFB mode, safety vetoes are applied to all the EIS-access and EIS-beam/EIS-machine elements. It is an intermediate mode. In BEAM mode, safety vetoes are applied to all the EIS-access elements, safety vetoes are removed from all the EIS-beam/EIS-machine/EIS-external elements. BEAM operations are allowed in the inter-locked zones.

5.8.3 *Requirements for the PPS of EA1 and EA2 primary beam zones*

The requirements for the PPS of the EA Primary zones EA1 and EA2 concern the following elements:

- i) Access sectorization.
- ii) EIS-beam important safety elements of the machine against radiation exposure hazard.
- iii) External safety conditions associated with the new EA ventilation system.

5.8.3.1 New access sectorization for EA1 and EA2

The new EA1 beam layout aims at reducing the exposure to radiation of the personnel. In the new layout, the EA1 beam area is divided into a ‘primary area’ and ‘mixed area’, and the current single access sector is divided into three sectors: one for the mixed area (S1), giving access to the EA primary zone via the Access Point, and two sectors for the ‘primary area’ (S2, S3). Additionally, a corridor is created by opening the shielding blocks, giving direct access from EA1 to the blind sector area (accessible only through IRRAD before LS2) and therefore also to the EA2 external envelope. EA1 and EA2 are now connected with an ‘inter-zone door’ which allows passage in case of emergency (see Fig. 5-17 and Fig. 5-18).

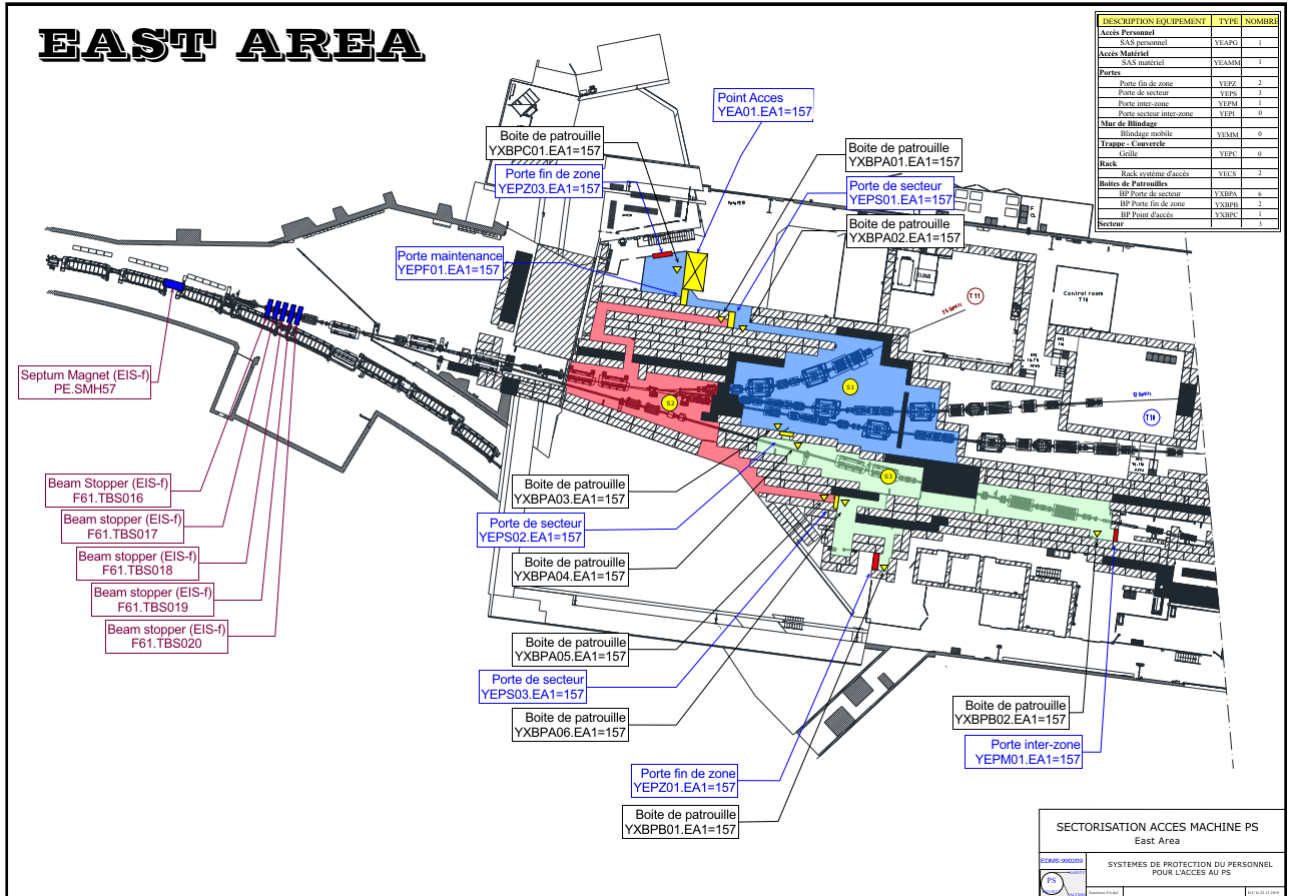


Fig. 5-17: Future access sectorization of the EA1 East Area primary beam zone.

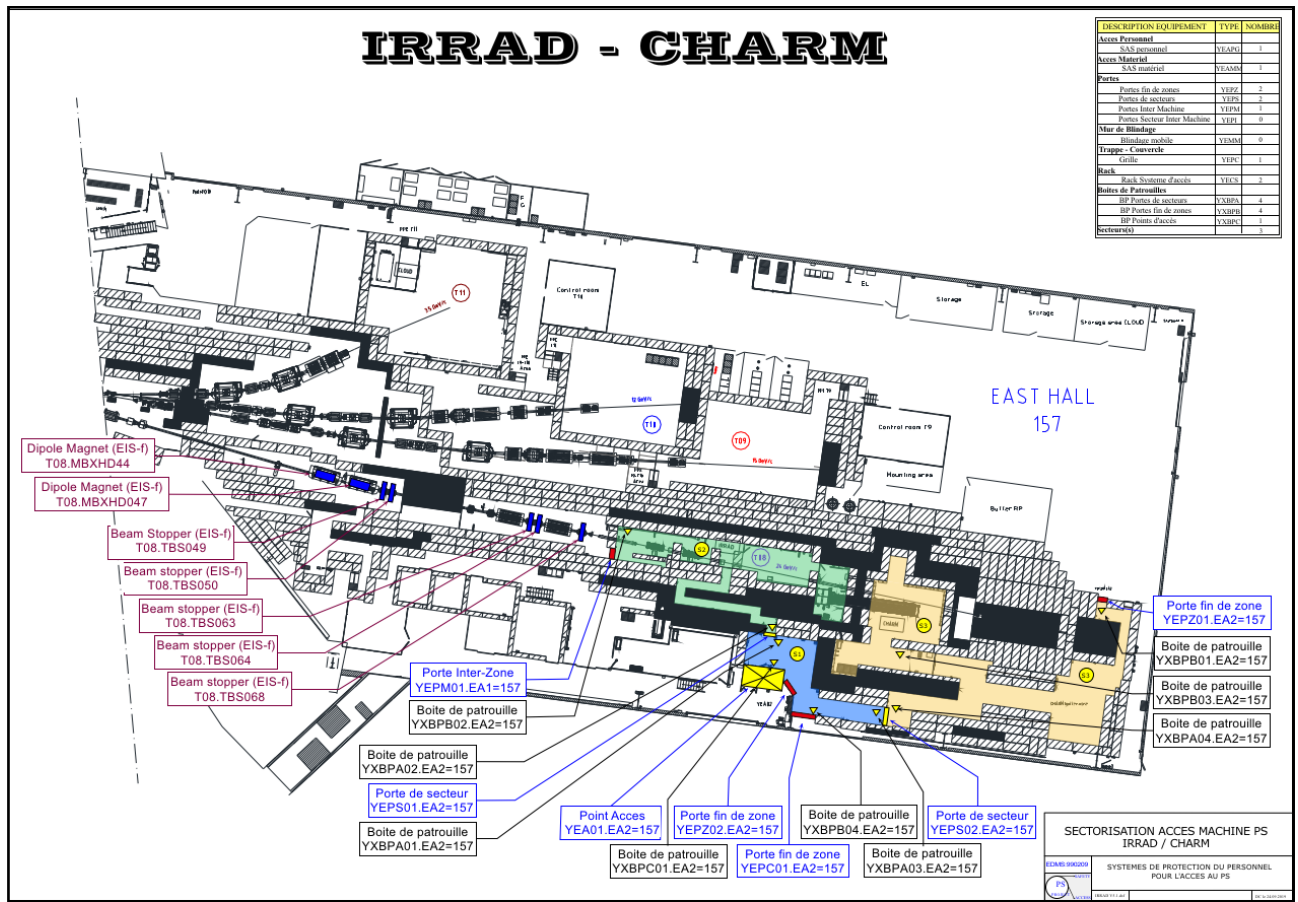


Fig. 5-18: Future access sectorization of the EA2 East Area primary beam zone.

5.8.4 Implementation of requirements for the EA1 and EA2 PPS

The EAR requirements do not question the current PS Complex PPS architecture, equipment types, and functionalities of the EA1 and EA2 PPS, which are described in the technical specifications in Ref. [23].

The architecture of the PS Complex and Experimental Area PPSs is presented in Fig. 5-19, and is composed of the following four levels, each ensuring a set of functions:

- i) Operation and supervision.
- ii) Central computing and safety infrastructure.
- iii) Zone safety controller.
- iv) Zone equipment.

Functions iii) and iv) exist specifically for each PS interlocked zone (safety chain). Two independent and redundant interlocked paths, a programmable logic controller (PLC), and a hardwired loop, ensure the PPS safety interlocks.

The PS PPSs central computing and safety infrastructure is located in Building 271. The EA1 and EA2 EIS important safety elements (access, beam, external) signals are cabled individually to their specific safety chain controller racks located in Building 271.

Due to the EAR project during LS2, all of the PPS EA1 installation located in Building 157 will be dismantled and re-installed according to the EAR requirements [17]. As presented in Section 5.8.3.1, the PPS EA2 is only slightly modified, and EAR works do not require dismantling of any PPS EA2 elements.

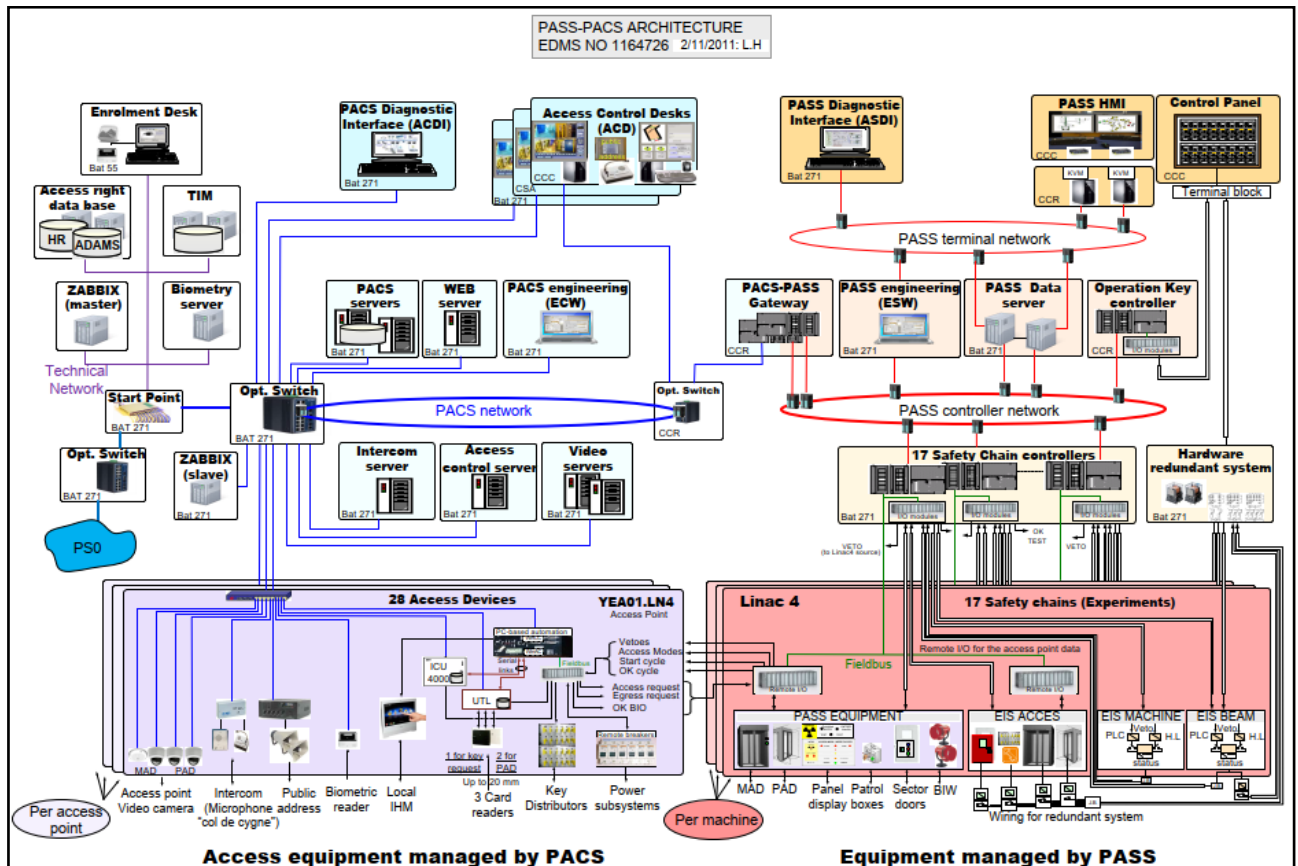


Fig. 5-19: PS Complex personnel protection system architecture.

5.8.5 Requirements for the EA experimental areas access safety systems

5.8.5.1 Scope of the renovation

An access control and safety system is currently operational in the three experimental areas (T09, T10, and T11). It ensures safe access and beam in those three independent experimental areas. Access to an experimental area is done via an access control door, known as PPE. Each area has at least one emergency door, known as PPX (personnel protection exit) that is also supervised by the access system. The PPE is equipped with a display panel (at the entry side, screen, and access) that provides the following functions.

- i) Exploitation modes console.
- ii) Safety veto management.
- iii) Chain tests management.
- iv) Views to show the status of the area and access and beam conditions, events log, and technical alarms.

The modifications in the EA experimental areas [18], can be summarized as follows:

- i) T09 and T10: position of the PPEs changed due to modification of the walls in the T10 and T09 areas.
- ii) A new zone, T09-10 will be created consisting of a PPE and a PPX: following the latest RP simulation studies for T09-10, a more restricted configuration of the T09-T10 experimental area PPE will be required. Only authorized persons will be able to change the operation mode (from CLOSED to ACCESS mode) by presenting their badge.

iii) T11: the current PPX will be removed, and a new emergency exit will be installed to allow access the crinoline. The position of the PPE changes also.

A new generation of beam stopper dumps will be installed in new positions. Table 5-7 presents the list of EIS related to the EA experimental areas and Fig. 5-20 presents the future layout.

Table 5-7: EA experimental area EIS.

	T09-10	T09	T10	T11
EIS-Access	PPE T09-10 PPX T09-10	PPE T09	PPE T10	PPE T11 PPX T11
EIS-Machine	T09.TBS017 T10.TBS019	T09.TBS017	T10.TBS019	T11.TBS04

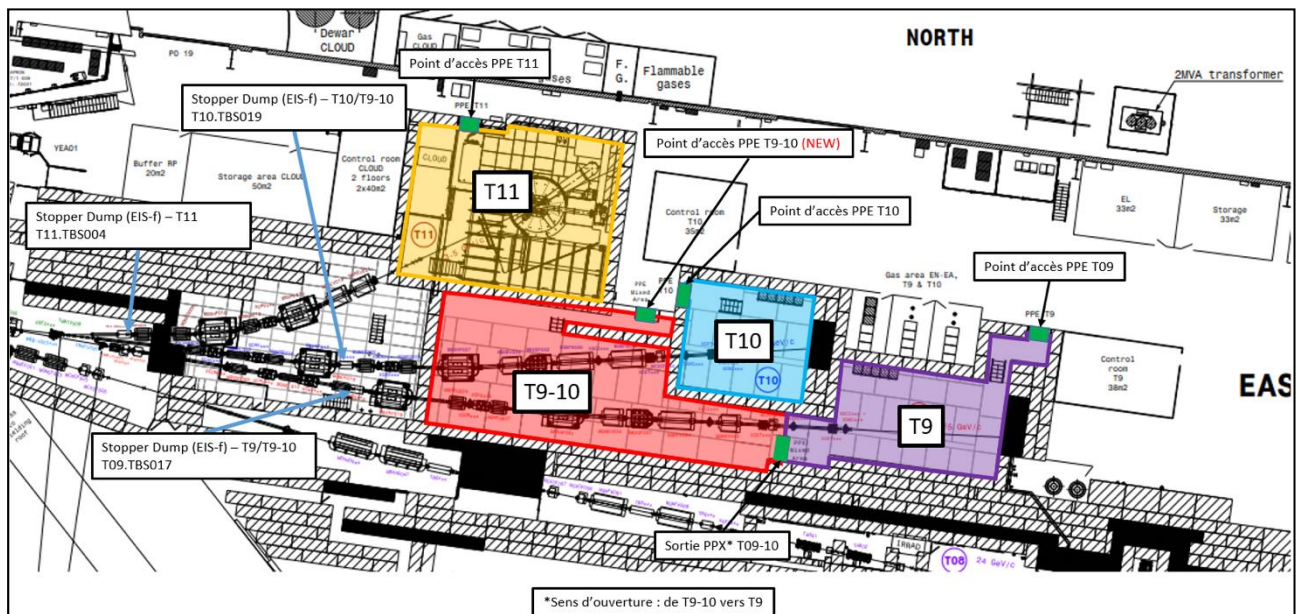


Fig. 5-20: EA experimental areas future layout.

5.8.5.2 PPEs principles

The experimental areas are considered secondary beam zones according to the radiological risk, which is lower than in the primary beam areas. Therefore, only one EIS beam [14] is deemed necessary to interlock the beam. Acceptable EIS can be both physical beam stoppers and interlocks on steering dipole magnet power supplies.

Given the energy of the particles and the low intensity of the beams in the EA experimental areas, beam stoppers are foreseen as EIS, and they must be 'fail-safe', i.e. safe for access when not powered. When a zone has to be accessed, the EIS must be confirmed as being in the 'safe' position. In case of danger detected in the access system, the interlock acts both on the EIS of the area concerned, but also on the upstream interlocked EIS.

The upstream interlock principle also applies. The access safety system will interlock the upstream area in the following situations:

- i) Danger for personnel: intrusion in BEAM mode with one EIS-Beam protecting the zone NOT in safe position, loss of safe position of one EIS-Beam of the zone during ACCESS mode.
- ii) At least one area in the 'Chain test' mode.
- iii) The experimental area operation and access modes are presented in Fig. 5-21.

The current access system is able to manage up to eight areas without major modifications of the central controller in Building 157; it manages the controller of each of the areas according to the defined safety matrix implementing the interlocks.

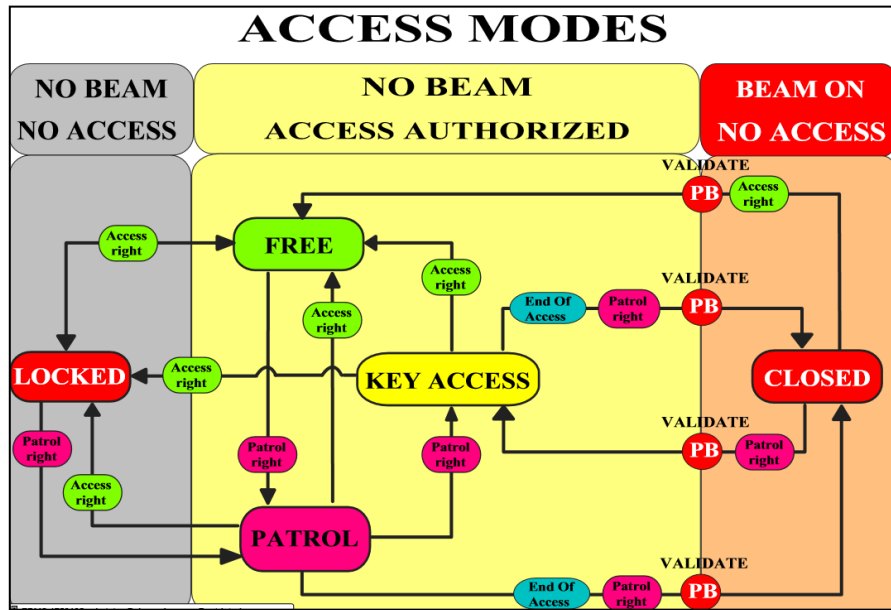


Fig. 5-21: Experimental area access modes – PPE front panel display.

5.9 Alarms

5.9.1 Introduction

In order to reduce the risk of fire and explosion for people, environment, and assets, the following safety system will be implemented in the frame of the renovation.

- i) Fire detection.
- ii) Gas detection.
- iii) Beam imminent warning.
- iv) Evacuation plan.

The safety functions of the above systems include early detection, warning occupants and firefighters in case of upset conditions, and automatic protection measures upon detection.

5.9.2 Fire detection

The new fire detection system in the East hall will be an extension of the existing infrastructure, connected to the SFDIN-00324 remote I/O control panel. A new ring connected fire detection loop will be installed as well as its field device and new on-line connected sirens.

Due to the layout of the building and in order to ensure early detection, no smoke detection will be installed under the ceiling but will be installed directly close to the beamlines.

The fire detection system will trigger the following actions:

- i) Level 3 alarms to the fire brigade.
- ii) Evacuation alarm.

- iii) Ventilation stop.
- iv) Smoke extraction. A fire risk analysis done in 2017 [19] explains this need.

5.9.3 Gas detection

The new gas detection system in the EA Facility (based on the same standard as in the North Area) will be the state of art SYNTEL distributed control system, which allows the rationalization of the main infrastructure. There will be one SYNTEL common central controller supervising the different experimental installations of the facility and the flammable and toxic gas distribution from the gas barrack to the mixing areas and patch panels. The gas distribution renovation is described in Ref. [20] (see Fig. 5-22).

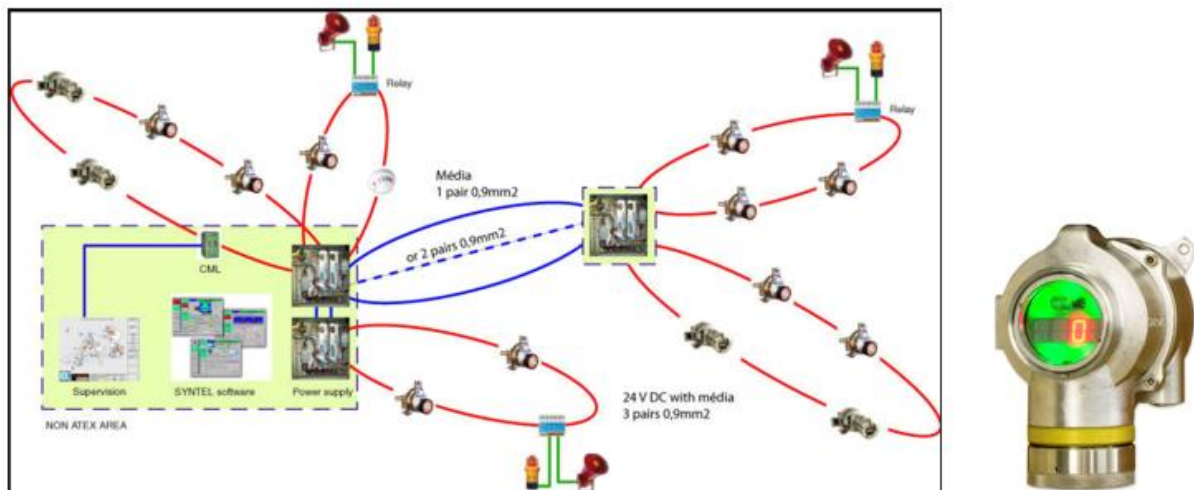


Fig. 5-22: SYNTEL gas detection – flexible technology with addressable devices.

The main infrastructure will consist of the SYNTEL central I/O panel, two racks in this specific configuration installed side by side.

5.9.4 Beam imminent warning (BIW)

The BIW is in use within the radioprotection primary area to warn people before the injection of high-energy particle beams in the machine. In the East Area facility, it triggers the PS access control system.

The new BIW in the East hall will be an extension of the existing infrastructure connected to the SESEV-00224. Fields device such as MACs (manual call point) and sirens will be installed as part of the project scope of work.

5.9.5 Evacuation

There will be an overall evacuation system for the whole East Hall. All the siren sounders will be launched at the same time. They will be connected and triggered by the SFDIN-00324.

A second evacuation system specifically designed for the risks in the primary RP areas of the EA facility will be connected, as presented above, to the SESEV-00224. There will be an interface between the two subsystems.

5.10 Gas systems

5.10.1 Introduction

The EA is supplied by a mixing area and gas piping network coming from a dedicated gases supply building located outside Building 157. This gas supply building is equipped with gas supply panels with connected gas bottles and banks, as shown in Fig. 5-23. It can provide many different types of gases (neutral, flammable) for fixed or temporary experiments in the hall [21][22].

The renovation includes the replacement of the gas supply system and all associated components (pipe and valves) as well as the creation of mixing areas for the premix and adjustment of gas parameters before use by detectors inside the beamlines. The renovation of the gas distribution infrastructure will allow the improvement and standardization of flammable gas safety from the supply building to the final user, in accordance with CERN regulations for safety. The system will follow the ATEX regulations and the global safety will be reinforced by the installation of closed gas racks equipped with ATEX air extraction and gas detection systems that enable the reduction of the ATEX area and restrict accidental leaks to defined volumes.

Another objective of this renovation action is to improve the use of gases between the mixing areas and beamlines (add insulated pipes and components for regulation). This is to in line with requests from many users [23] and also to avoid accumulation of gas equipment not controlled or not correctly assembled. The EA renovation also includes the removal of the gas delivery point to create a dedicated mixing area for the CLOUD experiment.

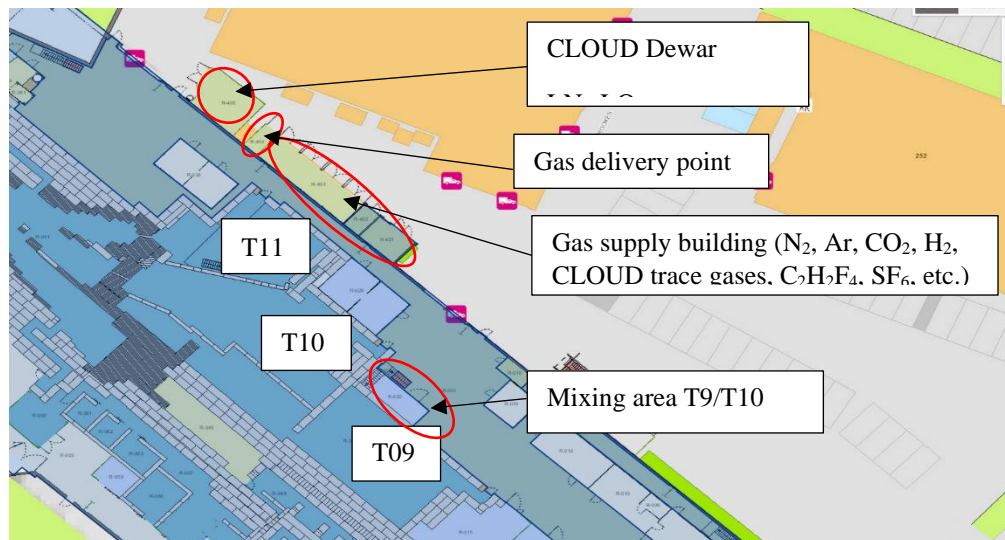


Fig. 5-23: Building 157, current gas distribution infrastructure.

5.10.2 Gas distribution infrastructure for the EA

5.10.2.1 Gas supply building (outdoor)

The content of the gas supply building located outside will be dismantled. The building will be equipped with new gas supply components with remote monitoring as well as a purge system with the possibility of recovering green-house gases (GHG).

The gas supply building will be split into four separate sections (Fig. 5-24):

- i) Gas mixing area and Dewar (LN_2 , LO_2) for the CLOUD experiment with trace gases (SO_2 , DMA, TMB, NAP, TOL):

- a. The trace gases will be relocated in a closed safety cabinet with air extraction and N₂ for inertion. The gas supply panels will be replaced by new panels in conformity with safety rules.
- ii) Gas supply area for Building 157 (N₂, CO₂, Ar, He):
- a. Replacement of old gas supply panels by new switch-over panels located inside closed rack equipped with remote monitoring and exhaust collection.
- iii) Gas supply area for flammable or heated gases:
- a. Three new closed flammable gas supply racks for T09, T10, and T11. These will be equipped with gas detection, air extraction, remote monitoring, purge collection, N₂ gas line for inertion, and a single gas supply panel (no backup).
- iv) Gas supply area H₂ (CLOUD):
- a. Change of old gas supply panels by new switch-over panels equipped with remote monitoring, exhaust collection, and N₂ gas line for inertion.

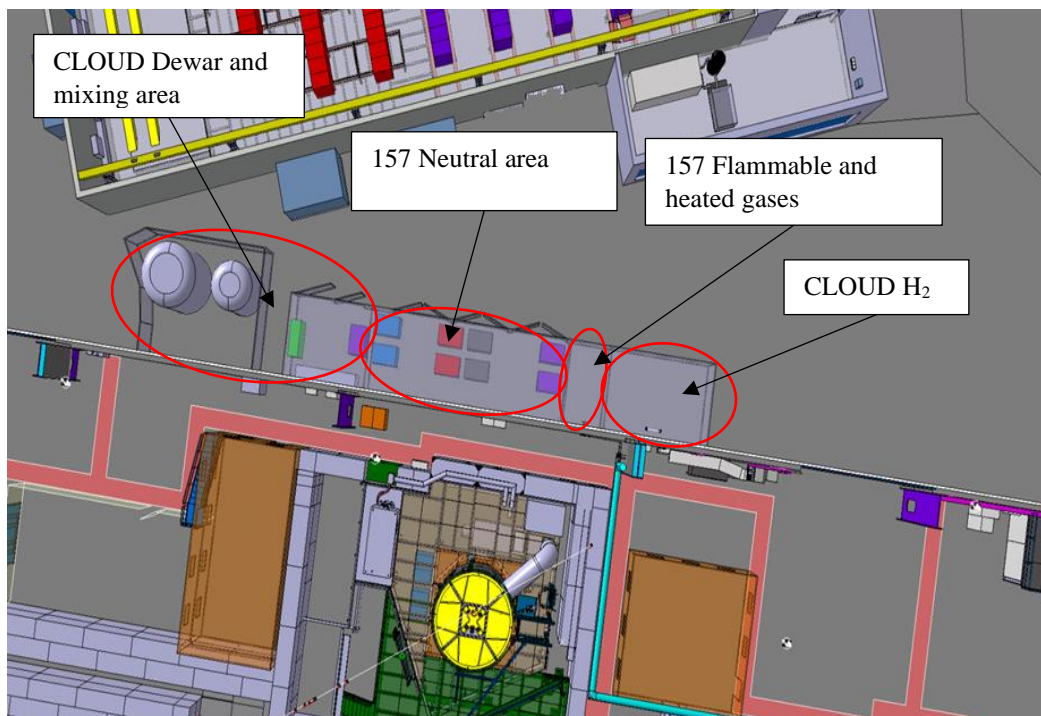


Fig. 5-24: Building 157, new gas distribution infrastructure (outdoor).

5.10.2.2 Gas mixing area T09/T10

The gas mixing area for T09 and T10 will be relocated and split into two dedicated mixing areas per beamline. Each dedicated area supplies the gases inside the beamline via insulated stainless-steel pipes. The closed patch panel for the beamline will be equipped with gas detection, ATEX air extraction, isolating valves, manometers, connectors, safety valves, and two exhaust pipes (flammable and neutral). The connection of the pipes from the patch panel to the experiment will be done via feedthroughs located in the patch panel to restrict a maximum of gas connection to the closed area with air extraction.

The T09/T10 mixing area will be equipped with (see Fig. 5-25):

- Two closed distribution rack for flammable and neutral gases with one linked to the patch panel in T09 and the other with the one in T10.
- Two enclosures (one for each experimental area) for setting up a temporary mixing gas rack (user's equipment).

- Two enclosures (one for each experimental area) for two premixed bottles (neutral gas quality up to 6.0) used for short periods.

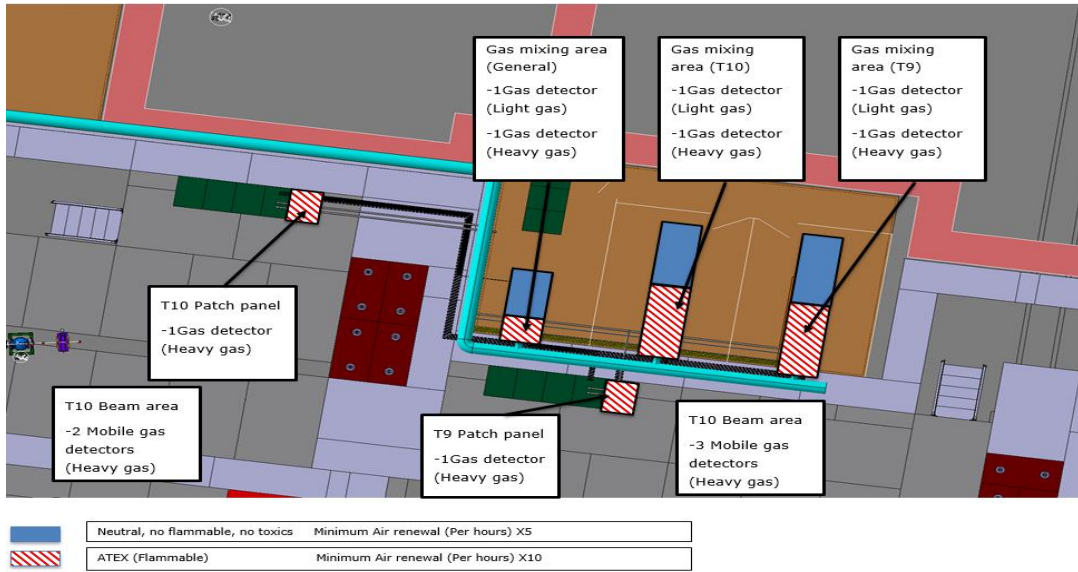


Fig. 5-25: Building 157 mixing area T09/T10.

5.10.2.3 Cherenkov's control rack

The Cherenkov control rack will provide gas (Ar, CO₂, optional refrigerant gases) for the four Cherenkovs inside the T09 and T10 beamlines. Figure 5-26 shows the gas racks organization.

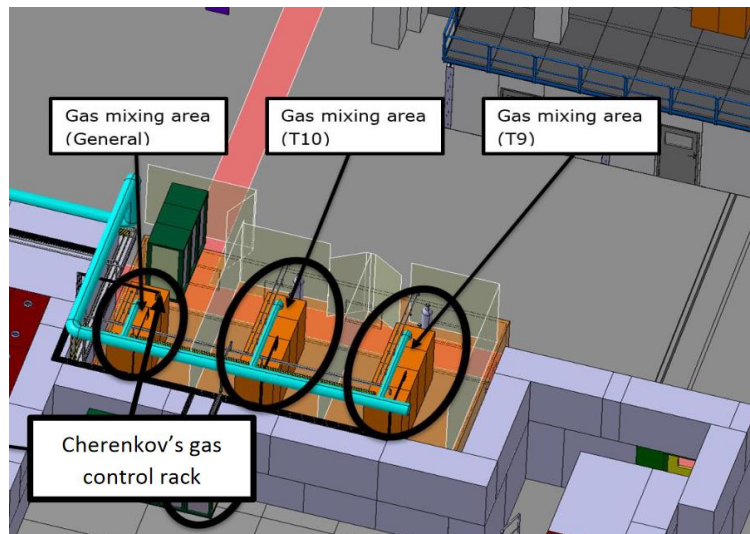


Fig. 5-26: Cherenkovs, gas rack location

References

- [1] E. Perez-Duenas, East Hall cladding upgrade (Building 157), IPP-2016-13, [EDMS 1591815](#) (2016).
- [2] C. Gasnier, B157 civil engineering – preliminary design, [EDMS 1817630](#) (2017).
- [3] F. Dragoni, East Area hall renovation: demineralised water cooling system user's requirements, [EDMS 1959531](#) (2018).

- [4] F. Dragoni, East Area hall renovation: demineralised water cooling system work package, [EDMS 1991994](#) (2018).
- [5] F. Dragoni, East Area Hall renovation: B157 and B251 ventilation system user's requirements, [EDMS 1964526](#) (2018).
- [6] F. Dragoni, East Area Hall renovation: Primary zone ventilation system user's requirements, [EDMS 1871830](#) (2018).
- [7] F. Dragoni, East Area Hall renovation: Primary zone and mixed area ventilation work package, [EDMS 2020740](#) (2018).
- [8] K. Papastergiou, Summary of circuits in the post-LS2 East Experimental Area, [EDMS 1546304](#) (2018).
- [9] J-C. Guillaume, East Hall renovation – Etude préliminaire sur la disposition des câbles DC, [EDMS 2016265](#) (2019).
- [10] E. Harrouch, Identification, labelling and disconnection procedure for obsolete cables in the East Area during YETS 2017-2018, [EDMS 1889546](#) (2018).
- [11] E. Harrouch, Demande d'enlèvement de câbles (DEC) dans le cadre de la rénovation de la zone Est, [EDMS 1962098](#) (2018).
- [12] D. Chapuis *et al.*, Spécification des éléments d'accès et inter verrouillage de la zone East Area, [EDMS 990209](#) (2014).
- [13] P.D. Chapuis *et al.*, Spécification des éléments d'accès et inter verrouillage de la zone IRRAD, [EDMS 990210](#) (2014).
- [14] A. Funken, Définition et inventaire des EIS-faisceau et EIS-machine, [EDMS 1182293](#) (2015).
- [15] L. Hammouti, PS personnel safety system technical requirement, [EDMS 977036](#) (2010).
- [16] L. Hammouti, PS complex access equipment technical requirements, [EDMS 1053017](#) (2010).
- [17] E. Harrouch, Evacuation distances in Primary, mixt and experimental area in the East Area (Building 157) after LS2, [EDMS 1892798](#) (2018).
- [18] E. Harrouch, Modification of the experimental areas access system and SUSI systems update, [EDMS 1948473](#) (2018).
- [19] A. Arnalich, B157 Renovation - Smoke extraction system - Performance-based fire risk assessment and design, [EDMS 1874322](#) (2017).
- [20] D. Jaillet, Gas distribution East Area (user requirement), [EDMS 1907012](#) (2018).
- [21] D. Jaillet, Flammable gas safety file: Gas mixing area after LS2 (Bt.157), [EDMS 1907283](#) (2018).
- [22] D. Jaillet, Flammable gas safety file: Gas barrack after LS2(Bt.157), [EDMS 1909609](#) (2018).
- [23] H. Wilkens, Gas requirements from experiments in the East Area, [EDMS 1907906](#) (2018).